Netter's Atlas of Human Physiology

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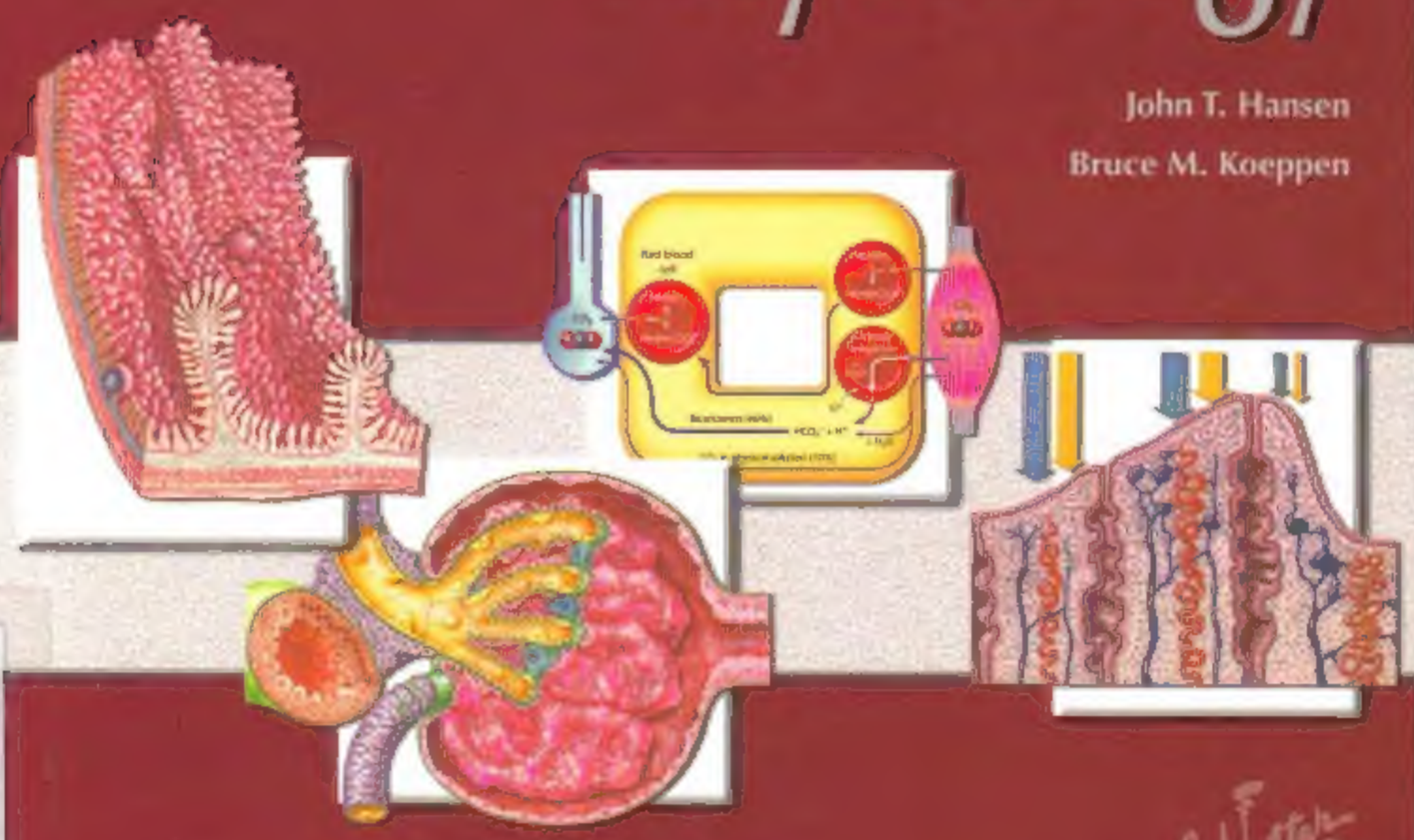


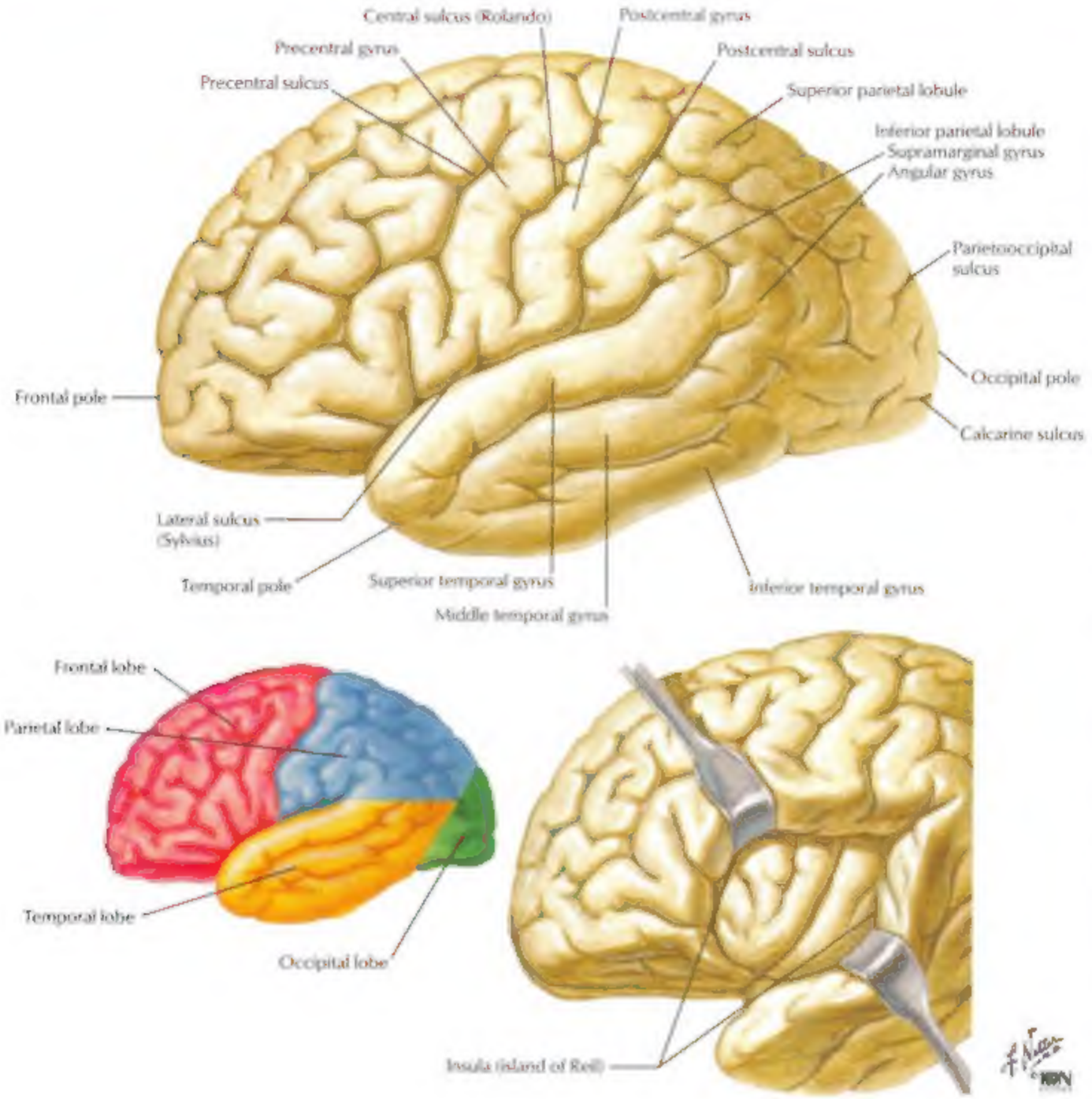


FIGURE 2.1 ORGANIZATION OF THE BRAIN: CEREBRUM

The cerebral cortex represents the highest center for sensory and motor processing. In general, the frontal lobe processes motor, visual, speech, and personality modalities. The parietal lobe processes sensory information; the temporal lobe, auditory and memory modalities; and the occipital lobe, vision. The cerebellum coordinates smooth motor activities and processes muscle position. The brainstem (medulla, pons, midbrain) conveys motor and sensory information and mediates important autonomic functions. The spinal cord receives sensory input from the body and conveys somatic and autonomic motor information to peripheral targets (muscles, viscera).

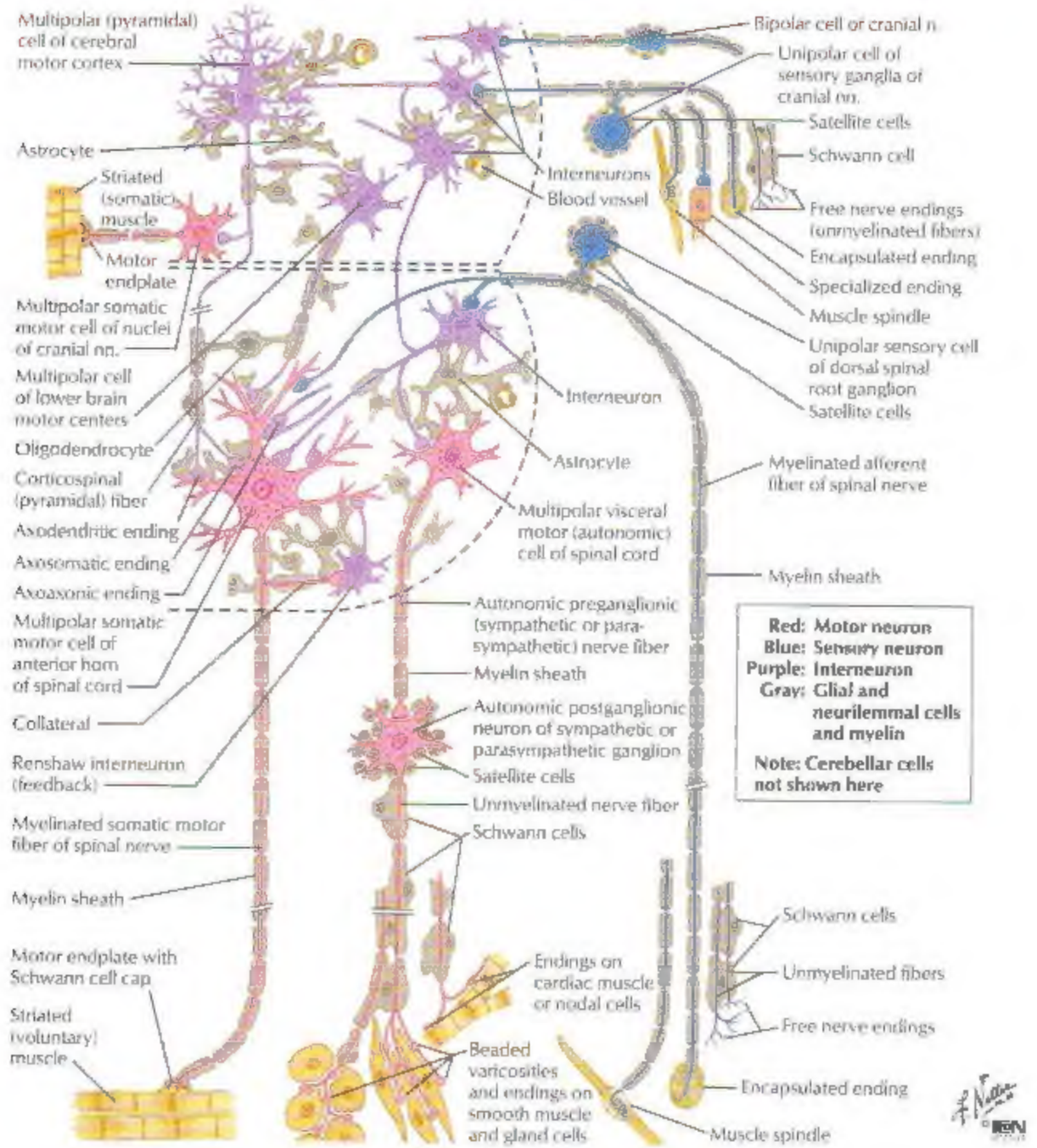


FIGURE 2.2 ORGANIZATION OF THE BRAIN: CELL TYPES

Neurons form the functional cellular units responsible for communication, and throughout the nervous system, they are characterized by their distinctive size and shapes (e.g., bipolar, unipolar, multipolar). Supporting cells include the neuroglia (e.g., astrocytes, oligodendrocytes), satellite cells, and other specialized cells that optimize neuronal function, provide maintenance functions, or protect the nervous system.

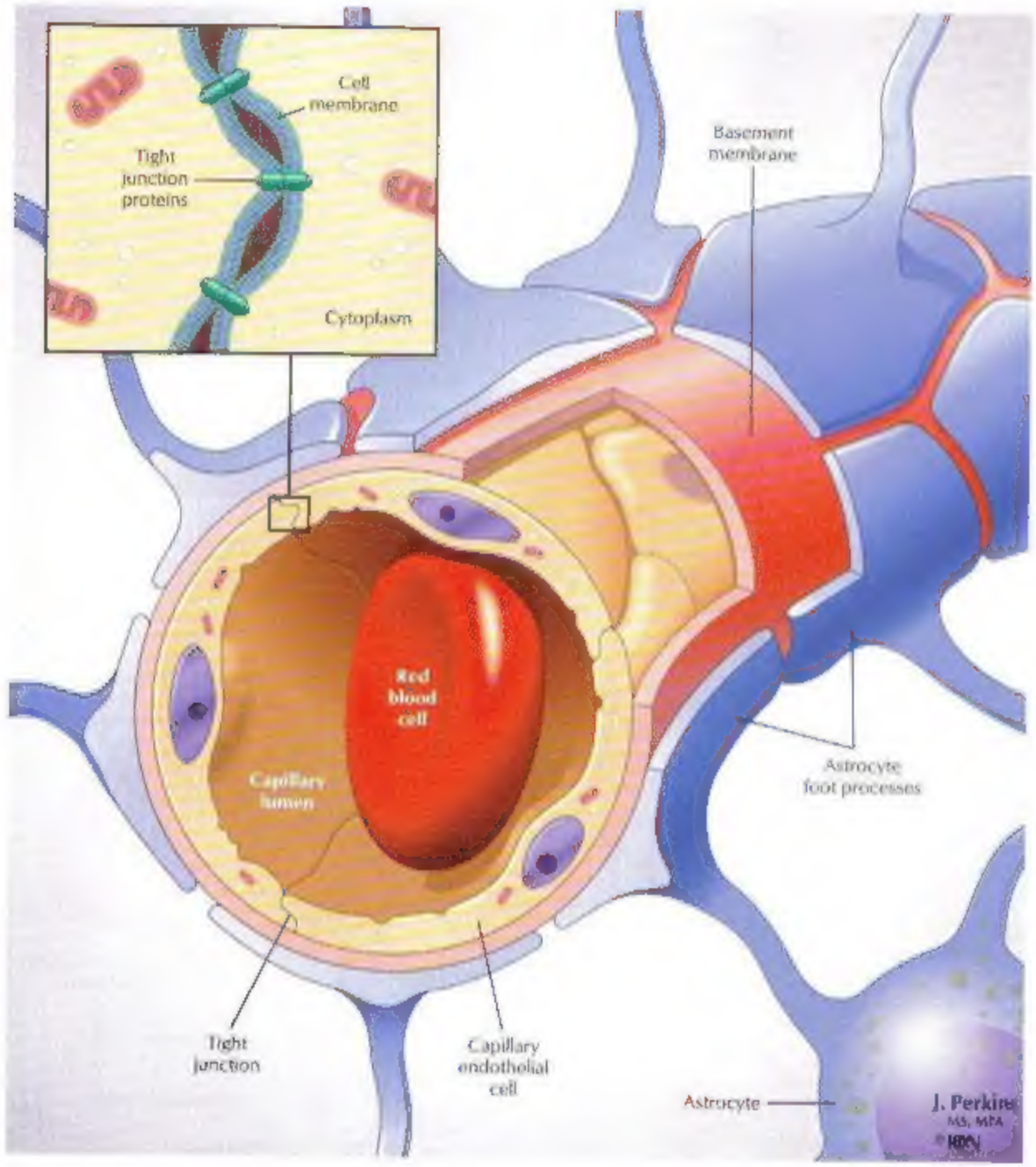


FIGURE 2.3 BLOOD-BRAIN BARRIER

The blood-brain barrier (BBB) is the cellular interface between the blood and the central nervous system (CNS: brain and spinal cord). It serves to maintain the interstitial fluid environment to ensure optimal functionality of the neurons. This barrier consists of the capillary endothelial cells with an elaborate network of tight junctions and astrocytic foot processes that abut the endothelium and its basement membrane. The movement of large molecules and other substances (including many drugs) from the blood to the interstitial space of the CNS is restricted by the BBB. CNS endothelial cells also exhibit a low level of pinocytotic activity across the cell, so specific carrier systems for the transport of essential substrates of energy and amino acid metabolism are characteristic of these cells. The astrocytes help transfer important metabolites from the blood to the neurons and also remove excess K^+ and neurotransmitters from the interstitial fluid.

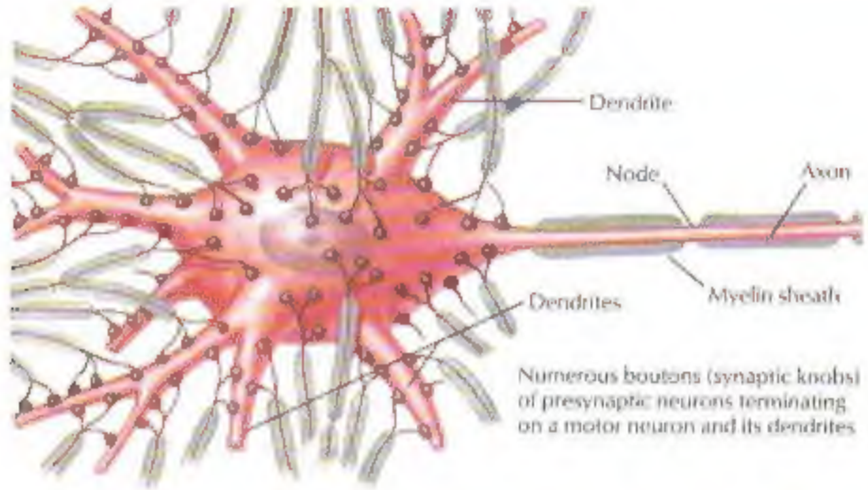


FIGURE 2.4 MORPHOLOGY OF SYNAPSES

Neurons communicate with each other and with effector targets at specialized regions called synapses. The top figure shows a typical motor neuron that receives numerous synaptic contacts on its cell body and associated dendrites. Incoming axons lose their myelin sheaths, exhibit extensive branching, and terminate as synaptic boutons (synaptic terminals or knobs) on the motor neuron. The lower figure shows an enlargement of one such synaptic bouton. Chemical neurotransmitters are contained in synaptic vesicles, which can fuse with the presynaptic membrane, release the transmitters into the synaptic cleft, and then bind to receptors situated in the postsynaptic membrane. This synaptic transmission results in excitatory, inhibitory, or modulatory effects on the target cell.

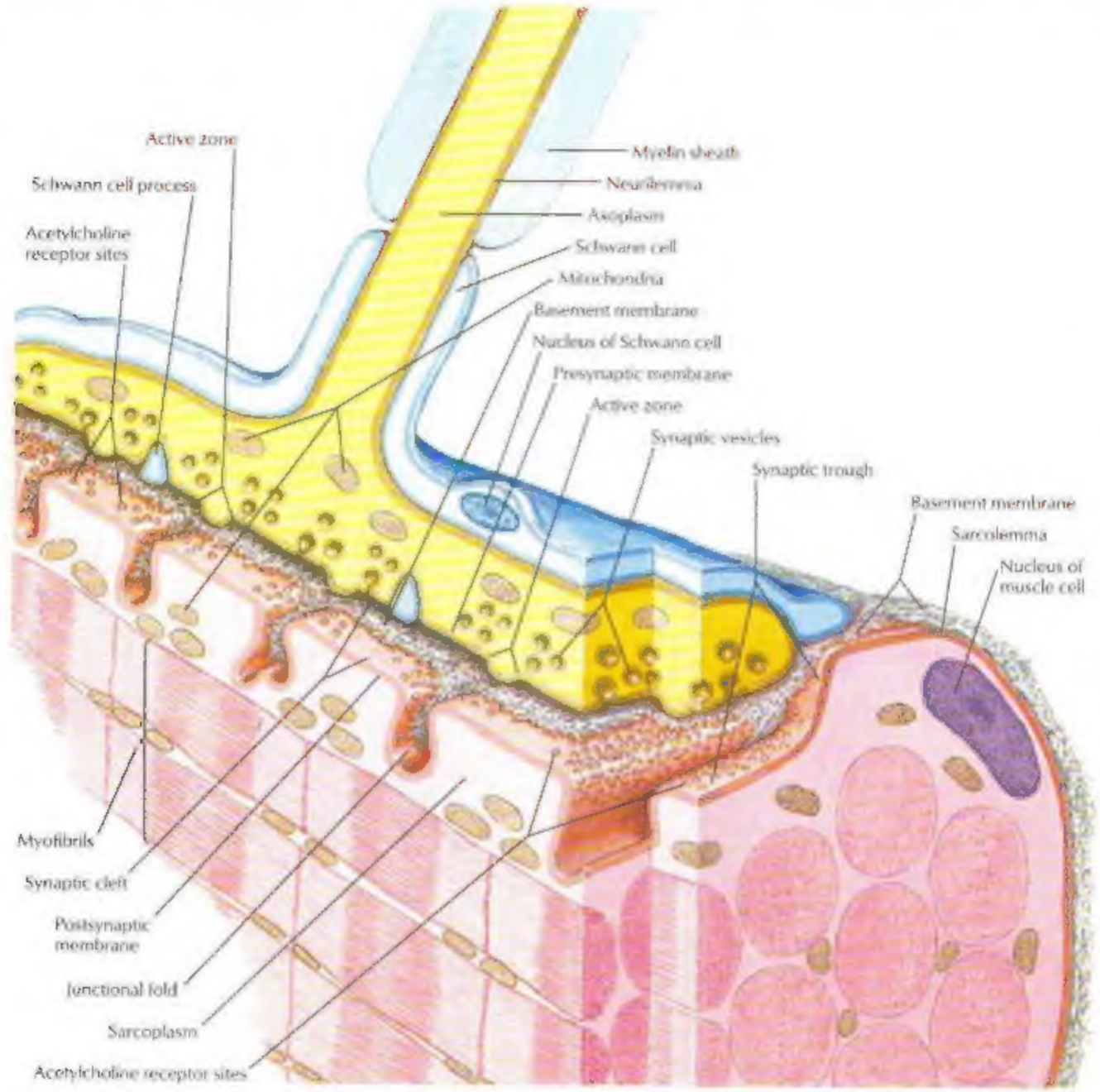


FIGURE 2.5 STRUCTURE OF THE NEUROMUSCULAR JUNCTION

Motor axons that synapse on skeletal muscle form expanded terminals called neuromuscular junctions (motor endplates). The motor axon loses its myelin sheath and expands into a Schwann cell–invested synaptic terminal that resides within a trough in the muscle fiber. Acetylcholine-containing synaptic vesicles accumulate adjacent to the presynaptic membrane and, when appropriately stimulated, release their neurotransmitter into the synaptic cleft. The transmitter then binds to receptors that mediate depolarization of the muscle sarcolemma and initiate a muscle action potential. A single muscle fiber has only one neuromuscular junction, but a motor axon can innervate multiple muscle fibers.

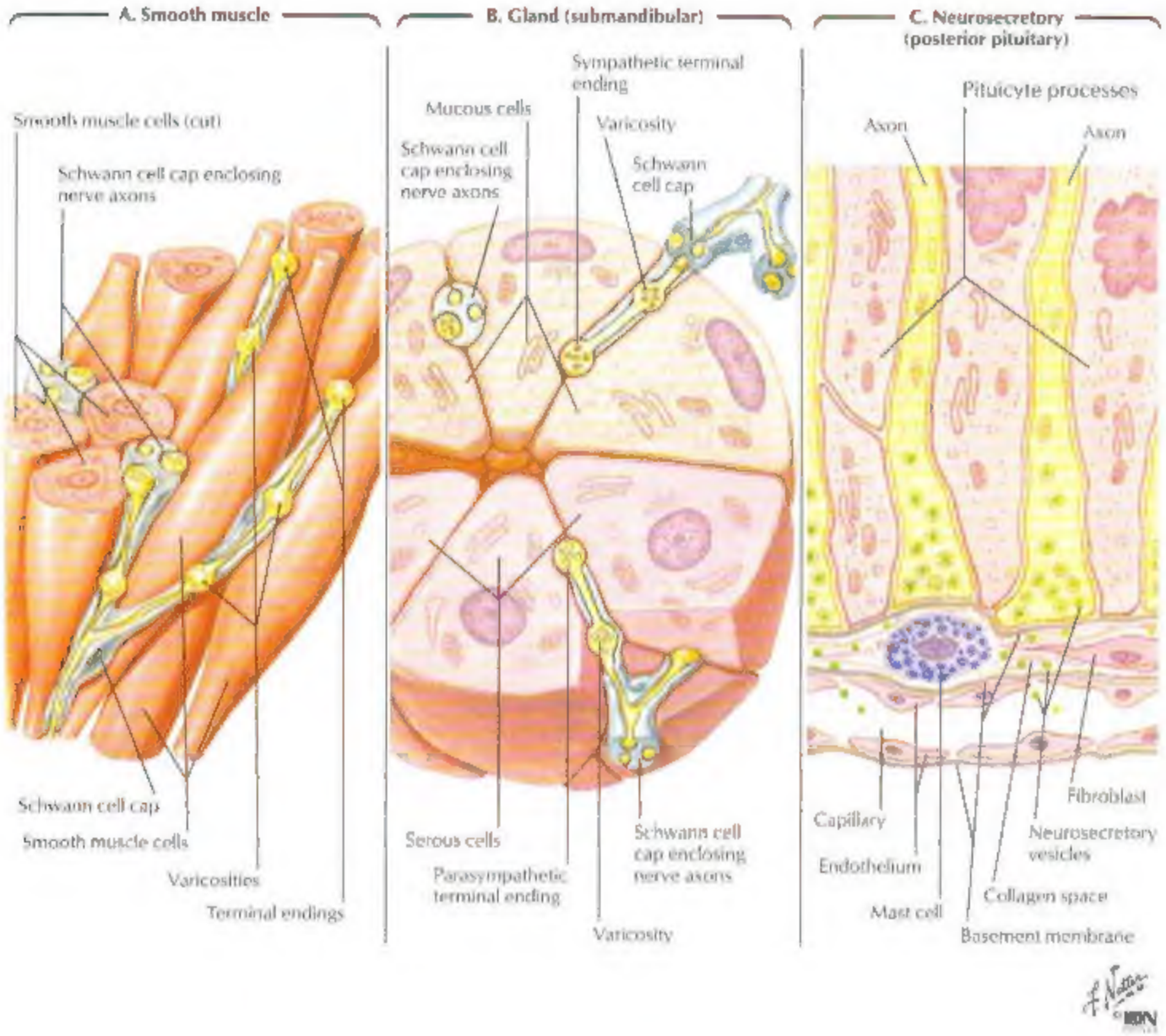


FIGURE 2.6 VISCERAL EFFERENT ENDINGS

Neuronal efferent endings on smooth muscle (A) and glands (B and C) exhibit unique endings unlike the presynaptic and postsynaptic terminals observed in neuronal and neuromuscular junction synapses. Rather, neurotransmitter substances are released into interstitial spaces (A and B) or into the bloodstream (C, neurosecretion) from expanded nerve terminal endings. This arrangement allows for the stimulation of numerous target cells over a wide area. Not all smooth muscle cells are innervated. They are connected to adjacent cells by gap junctions and can therefore contract together with the innervated cells.

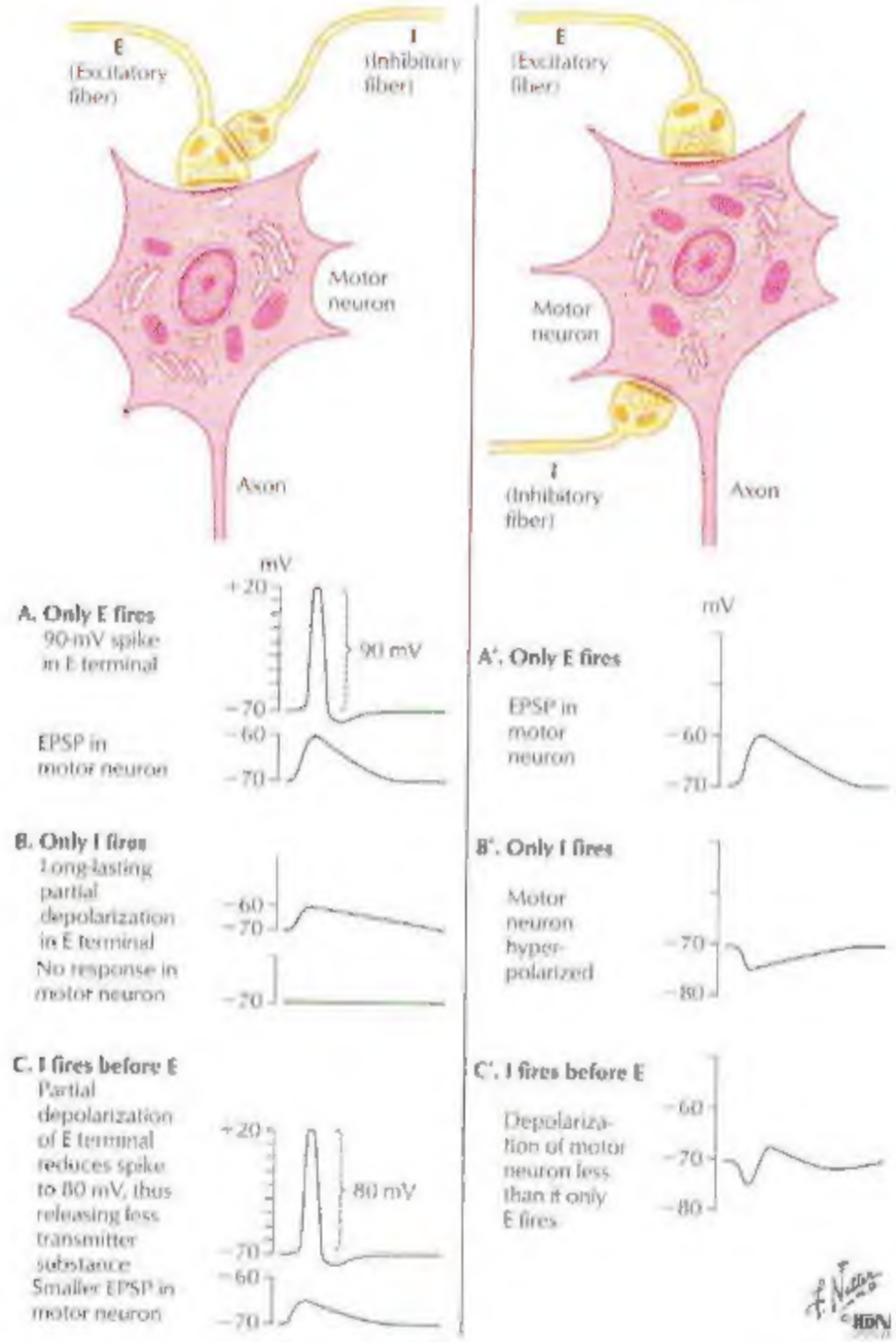


FIGURE 2.7 SYNAPTIC INHIBITORY MECHANISMS

Inhibitory synapses modulate neuronal activity. Illustrated here is presynaptic inhibition (left panel) and postsynaptic inhibition (right panel) at a motor neuron.

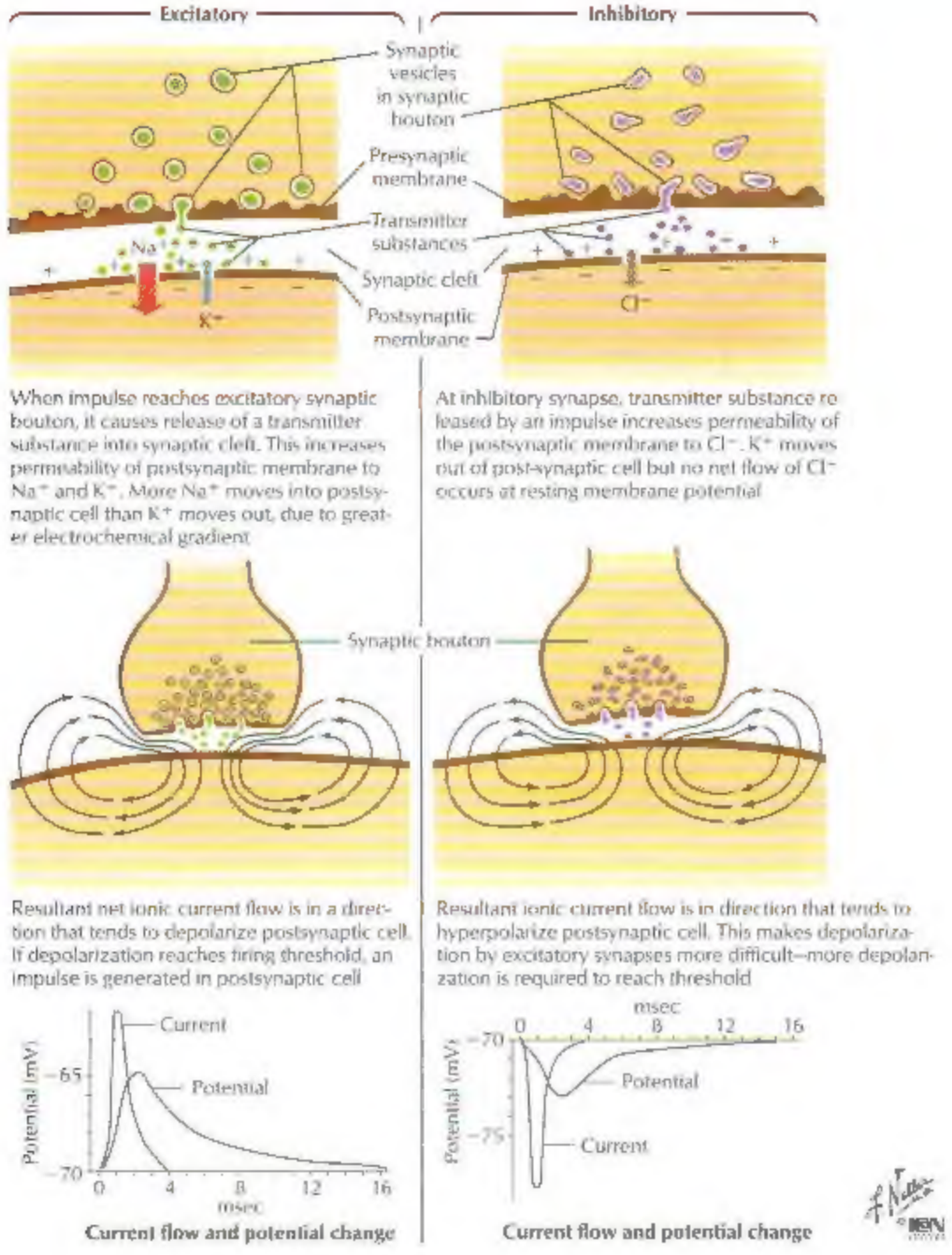
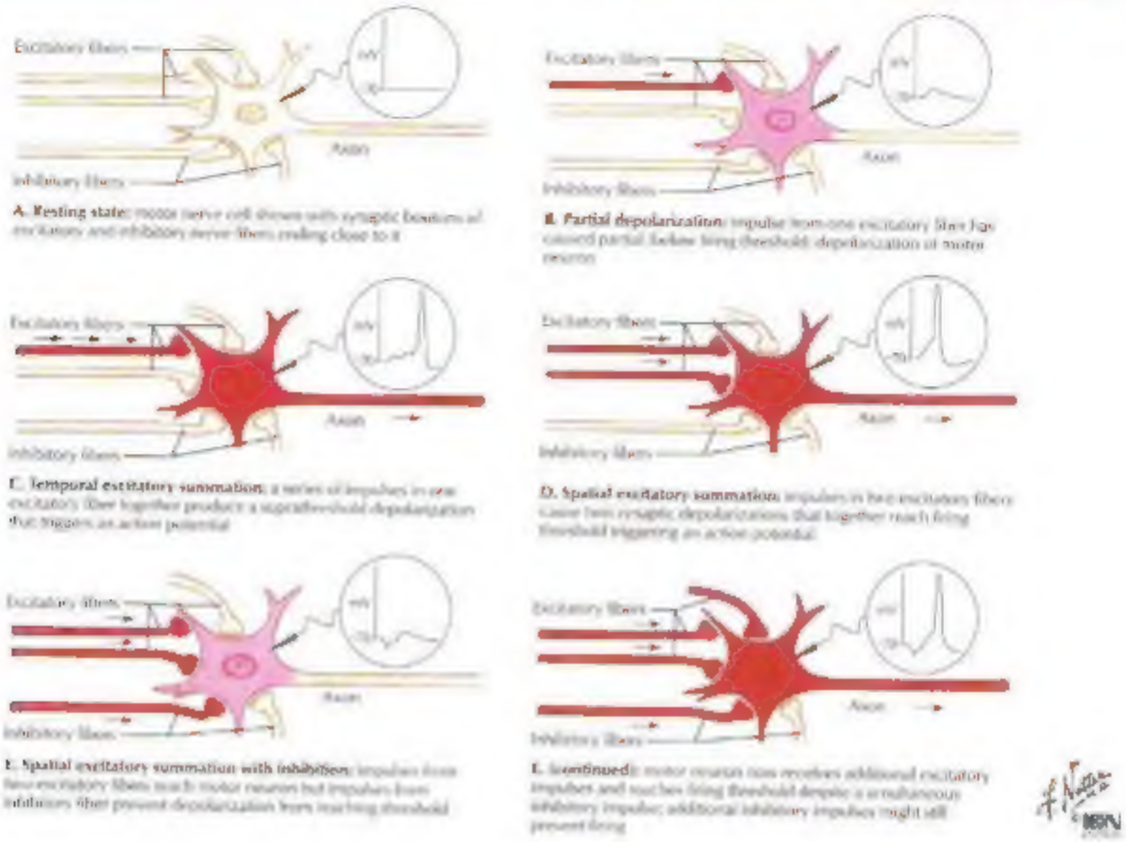


FIGURE 2.8 CHEMICAL SYNAPTIC TRANSMISSION

Chemical synaptic transmission between neurons may be excitatory or inhibitory. During excitation (left column), a net increase in the inward flow of Na^+ compared with the outward flow of K^+ results in a depolarizing potential change (excitatory postsynaptic potential [EPSP]) that drives the postsynaptic cell closer to its threshold for an action potential. During inhibition (right column), the opening of K^+ and Cl^- channels drives the membrane potential away from threshold (hyperpolarization) and decreases the probability that the neuron will reach threshold (inhibitory postsynaptic potential [IPSP]) for an action potential.



A. Resting state: motor nerve cell shown with synaptic boutons of excitatory and inhibitory nerve fibers ending close to it

B. Partial depolarization: impulse from one excitatory fiber has caused partial, below firing threshold, depolarization of motor neuron

C. Temporal excitatory summation: a series of impulses in one excitatory fiber together produce a suprathreshold depolarization that triggers an action potential

D. Spatial excitatory summation: impulses in two excitatory fibers cause two synaptic depolarizations that together reach firing threshold triggering an action potential

E. Spatial excitatory summation with inhibition: impulses from two excitatory fibers reach motor neuron but impulses from inhibitory fiber prevent depolarization from reaching threshold

E. (continued): motor neuron now receives additional excitatory impulses and reaches firing threshold despite a simultaneous inhibitory impulse; additional inhibitory impulses might still prevent firing

CHART 2.1 SUMMARY OF SOME NEUROTRANSMITTERS AND WHERE WITHIN THE CENTRAL AND PERIPHERAL NERVOUS SYSTEM THEY ARE FOUND

Transmitter	Location	Transmitter	Location
Acetylcholine	Neuromuscular junction, autonomic ganglia and ganglia, CNS	Gas Nitric oxide	CNS, GI tract
Biogenic amines Norepinephrine Dopamine Serotonin	Sympathetic endings, CNS CNS CNS, GI tract	Peptides β-Endorphins Enkephalins Antidiuretic hormone Pituitary-releasing hormones Somatostatin Neuropeptide Y Vasoactive intestinal peptide	CNS, GI tract CNS CNS (hypothalamus/posterior pituitary) CNS (hypothalamus/anterior pituitary) CNS, GI tract CNS CNS, GI tract
Amino acids γ-Aminobutyric acid (GABA) Glutamate	CNS CNS		
Purines Adenosine Adenosine triphosphate (ATP)	CNS CNS		

CNS, Central nervous system; GI, gastrointestinal.

FIGURE 2.9 TEMPORAL AND SPATIAL SUMMATION

Neurons receive multiple excitatory and inhibitory inputs. Temporal summation occurs when a series of subthreshold impulses in one excitatory fiber produces an action potential in the postsynaptic cell (panel C). Spatial summation occurs when subthreshold impulses from two or more different fibers trigger an action potential (panel D). Both temporal and spatial summation can be modulated by simultaneous inhibitory input (panel E). Inhibitory and excitatory neurons use a wide variety of neurotransmitters, some of which are summarized here.

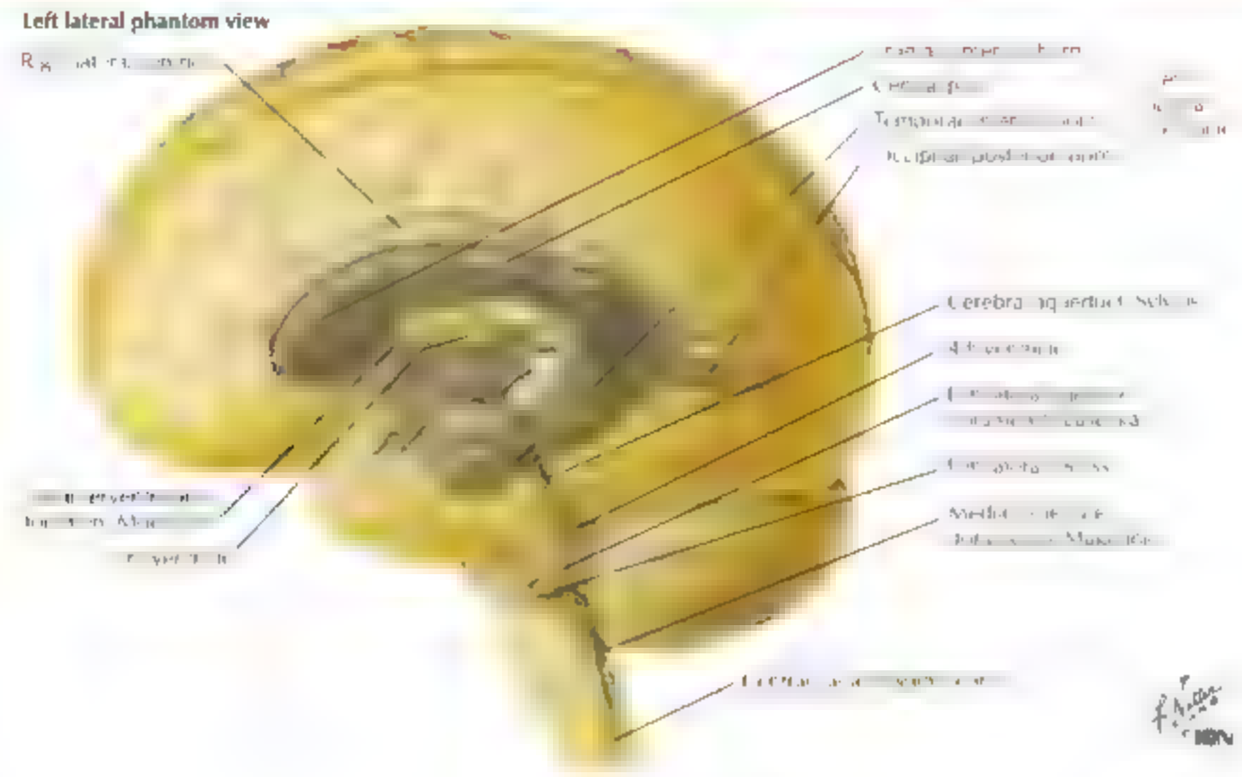


CHART 2.2 CSF COMPOSITION

	CSF	

FIGURE 2.10 BRAIN VENTRICLES AND CSF COMPOSITION

CSF circulates through the four ventricles: two lateral ventricles and the third and fourth ventricles, surrounding the brain and spinal cord. The ventricles are filled by CSF produced by the choroid plexus. Each day, the CSF

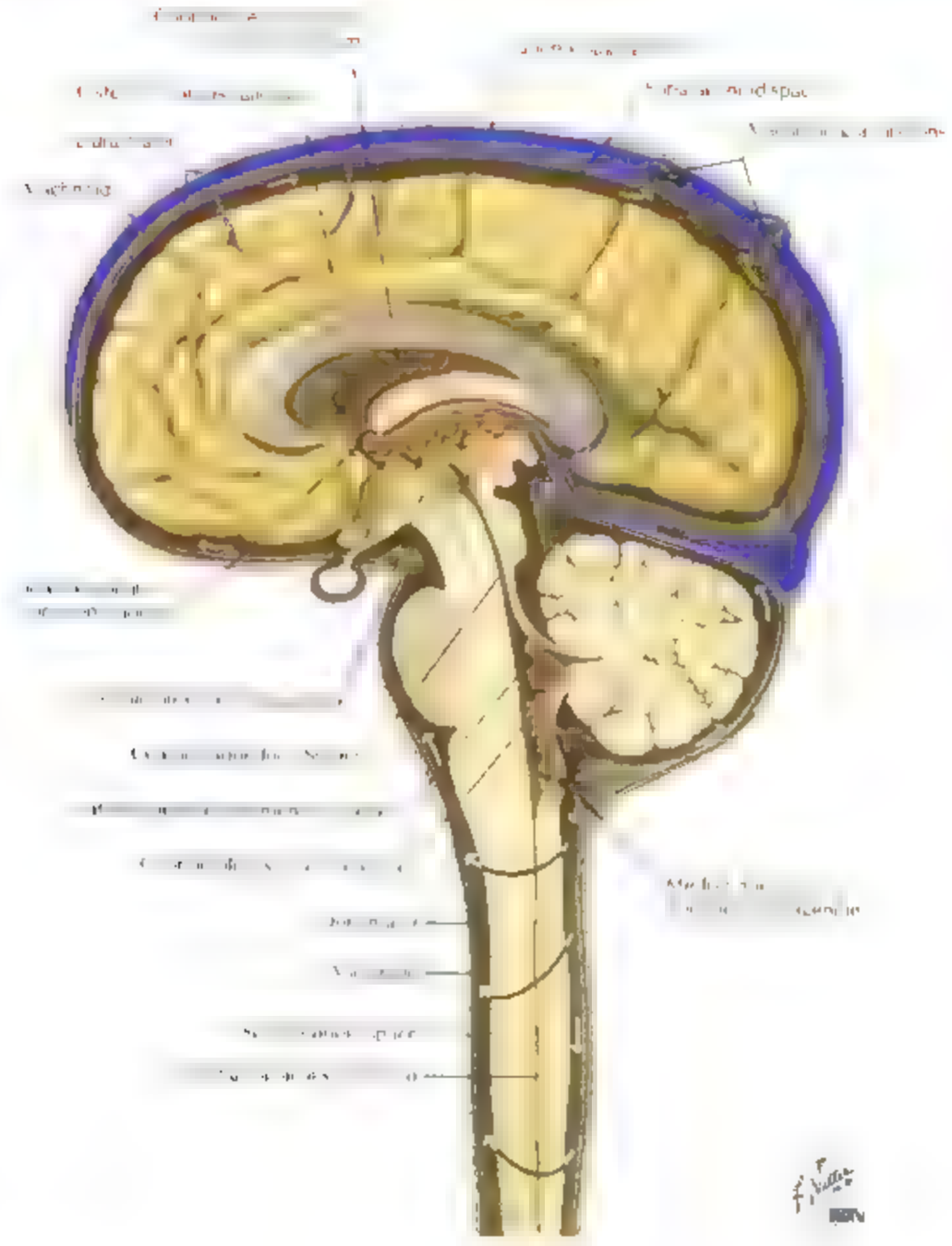


FIGURE 2.11 CIRCULATION OF CEREBROSPINAL FLUID

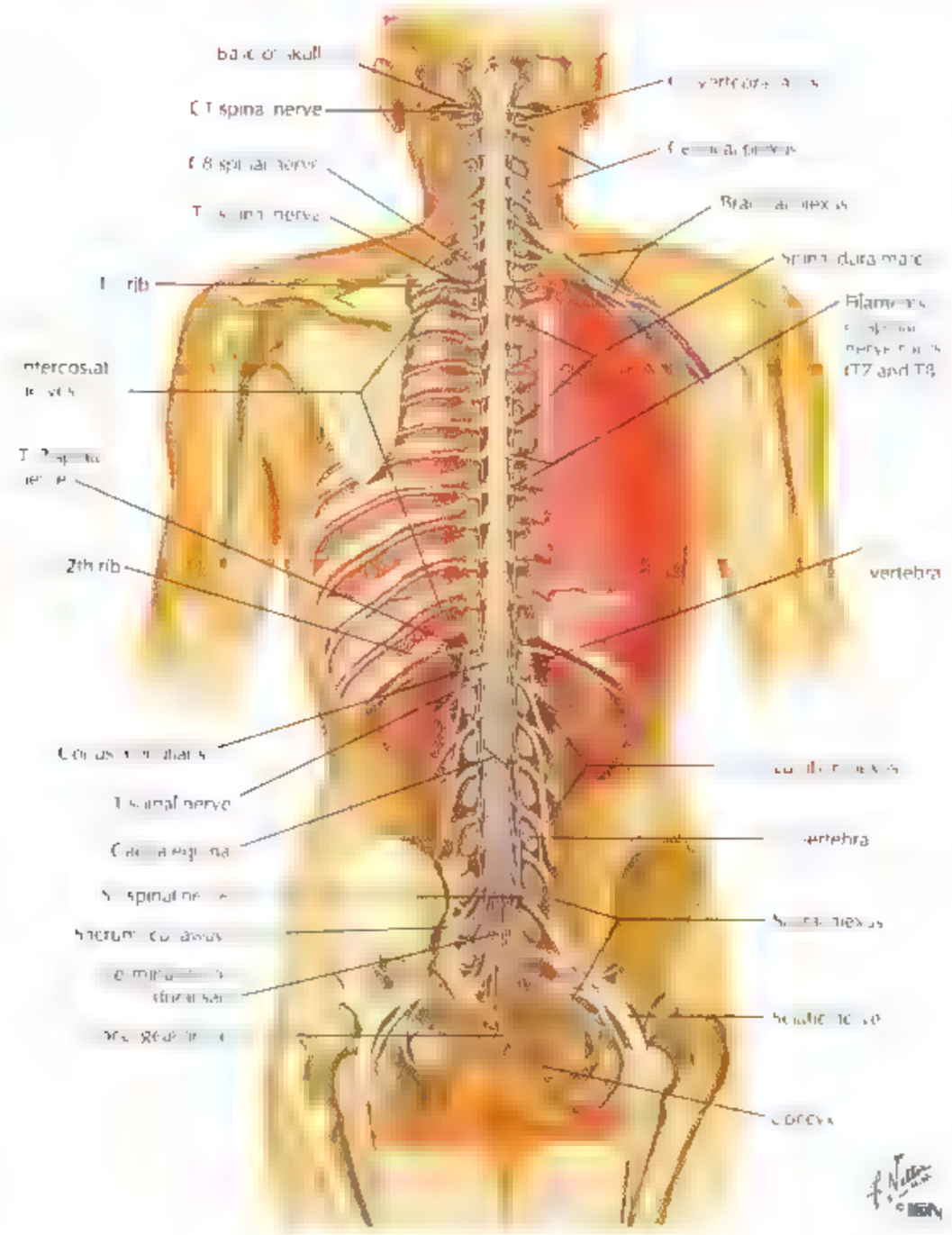


FIGURE 2.12 SPINAL CORD AND VENTRAL RAMI IN SITU

The spinal cord gives rise to 31 pairs of spinal nerves. Each nerve is connected to the spinal cord by a dorsal root and a ventral root. These nerves originate from the plexuses (networks) that distribute to the neck, cervical plexus; upper limb, brachial plexus; and pelvis and lower limb, lumbosacral plexus. Ventral rami of these spinal nerves innervate skeletal muscle and sensory fibers of the skin, skeletal muscles, and joints.

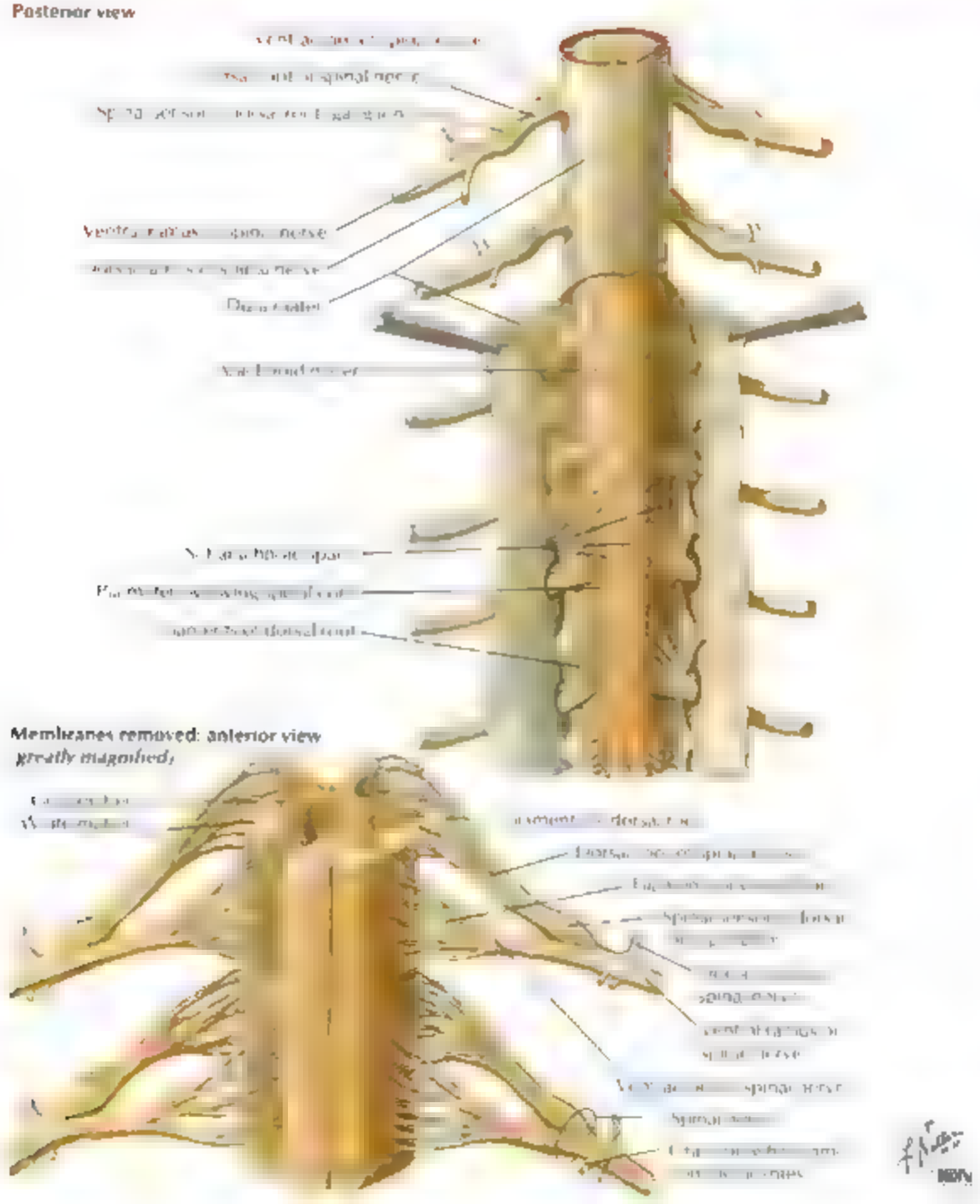


FIGURE 2.13 SPINAL MEMBRANES AND NERVE ROOTS

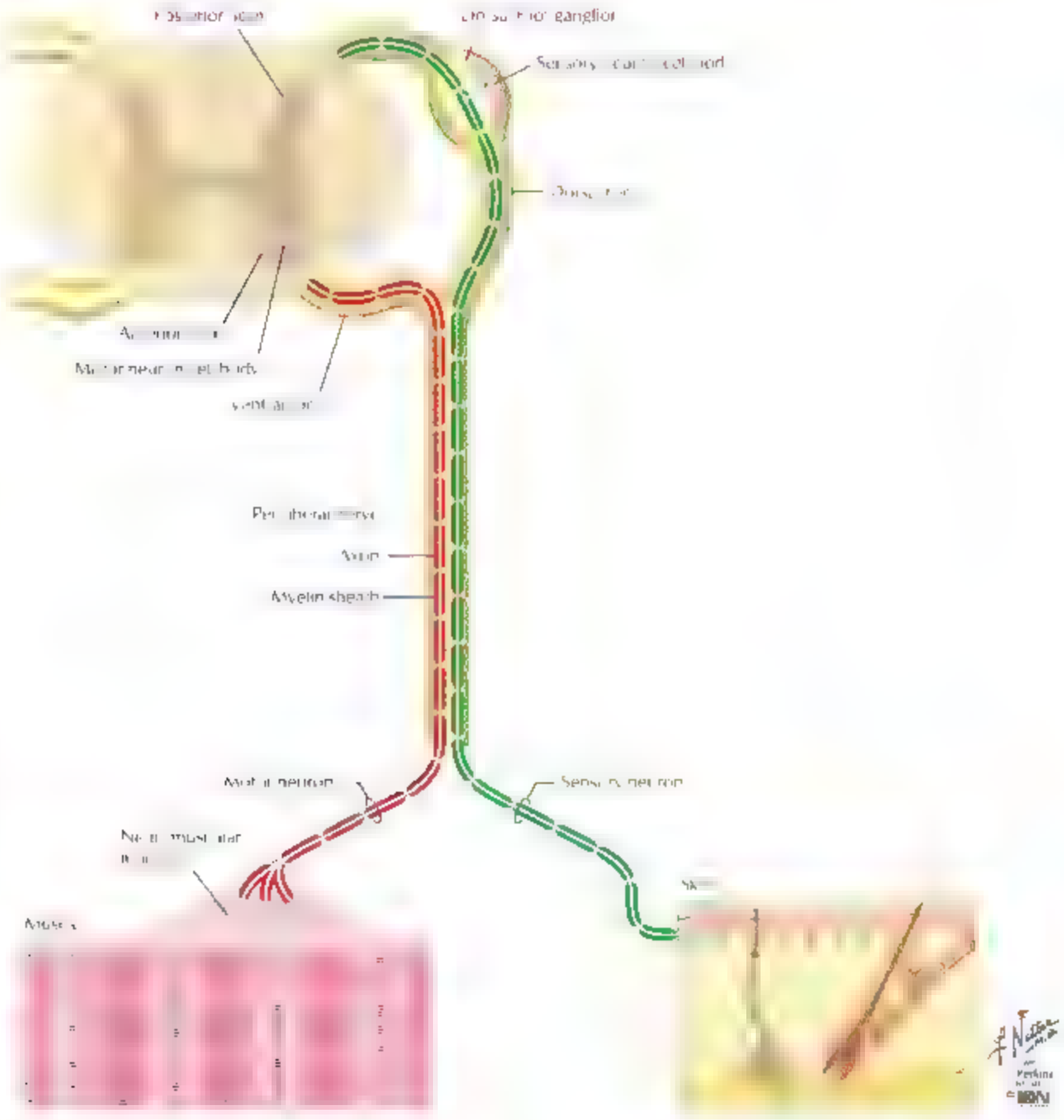


FIGURE 2.14 PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system (PNS) consists of all the neural elements on the outside of the CNS (brain and spinal cord) and provides the connections between the CNS and all other body organ systems. The PNS is subdivided into the somatic and autonomic components. The somatic component innervates skeletal muscle and skin and is shown here (see Figure [illegible] for the autonomic nervous system). The somatic component of the peripheral nerves contains both motor and sensory axons. Cell bodies of the motor neurons are found in the ventral horn of the spinal cord, whereas cell bodies of sensory neurons are located in the dorsal root ganglia.

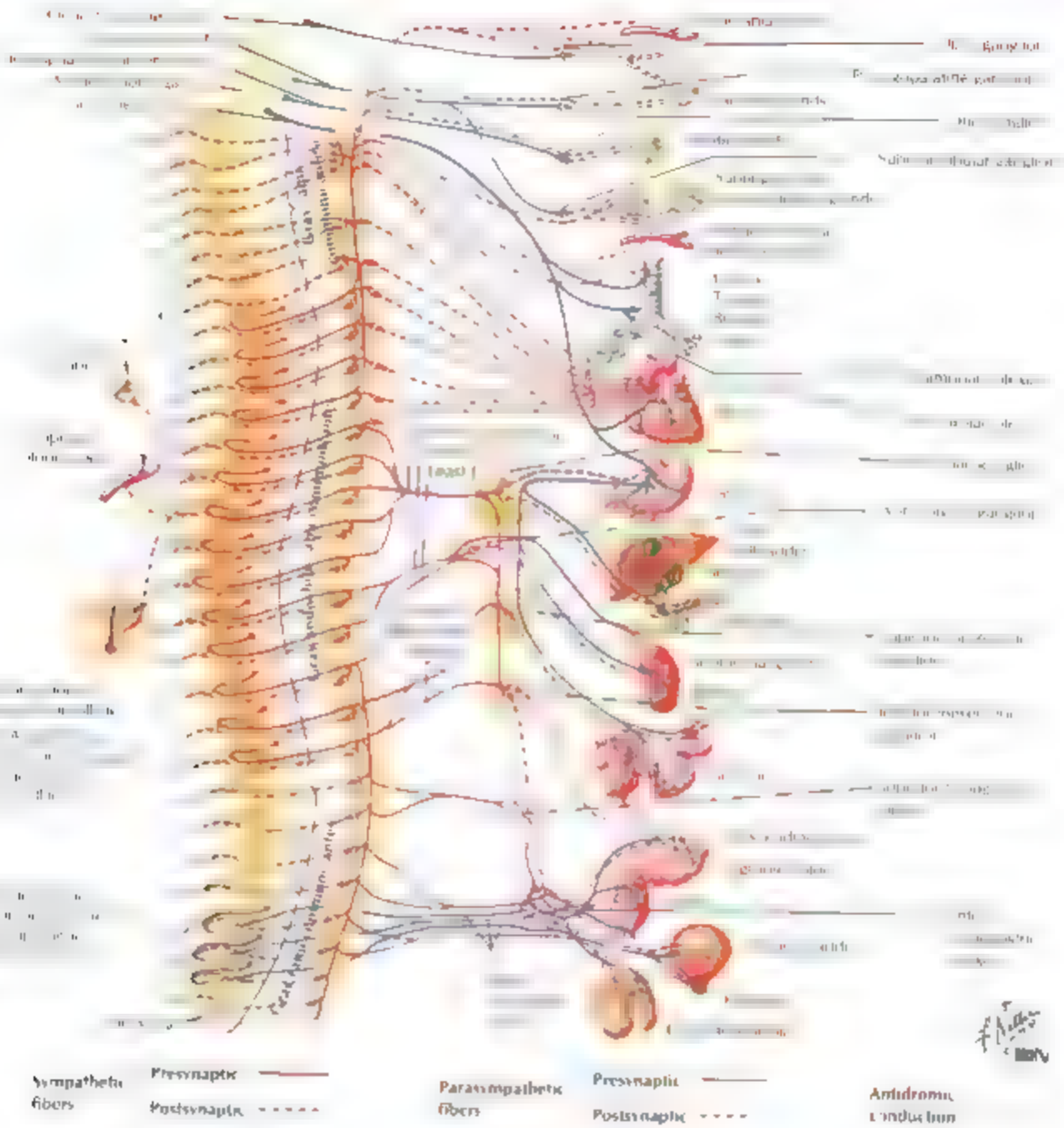


FIGURE 2.15 AUTONOMIC NERVOUS SYSTEM SCHEMA

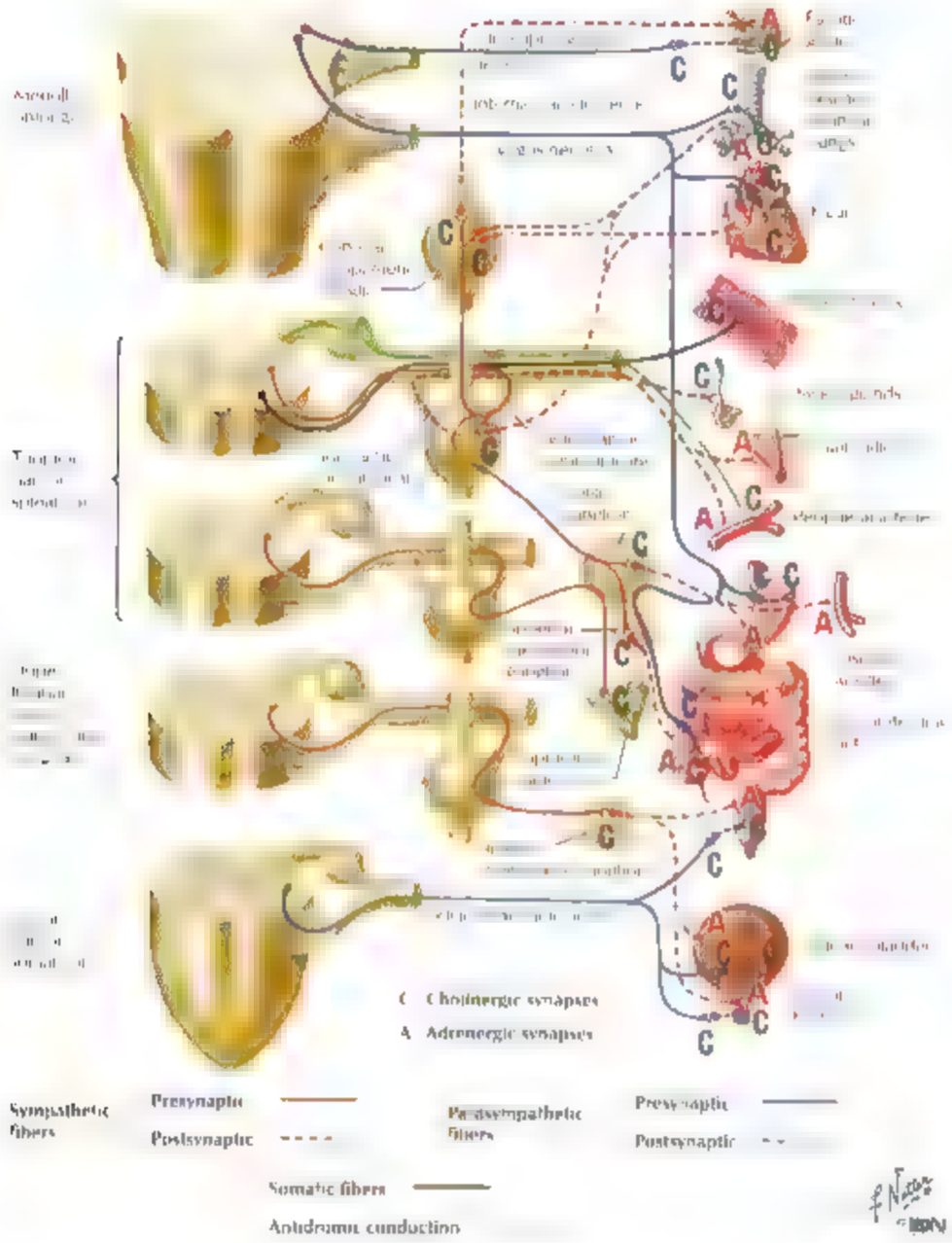


FIGURE 2.16 CHOLINERGIC AND ADRENERGIC SYNAPSES: SCHEMA

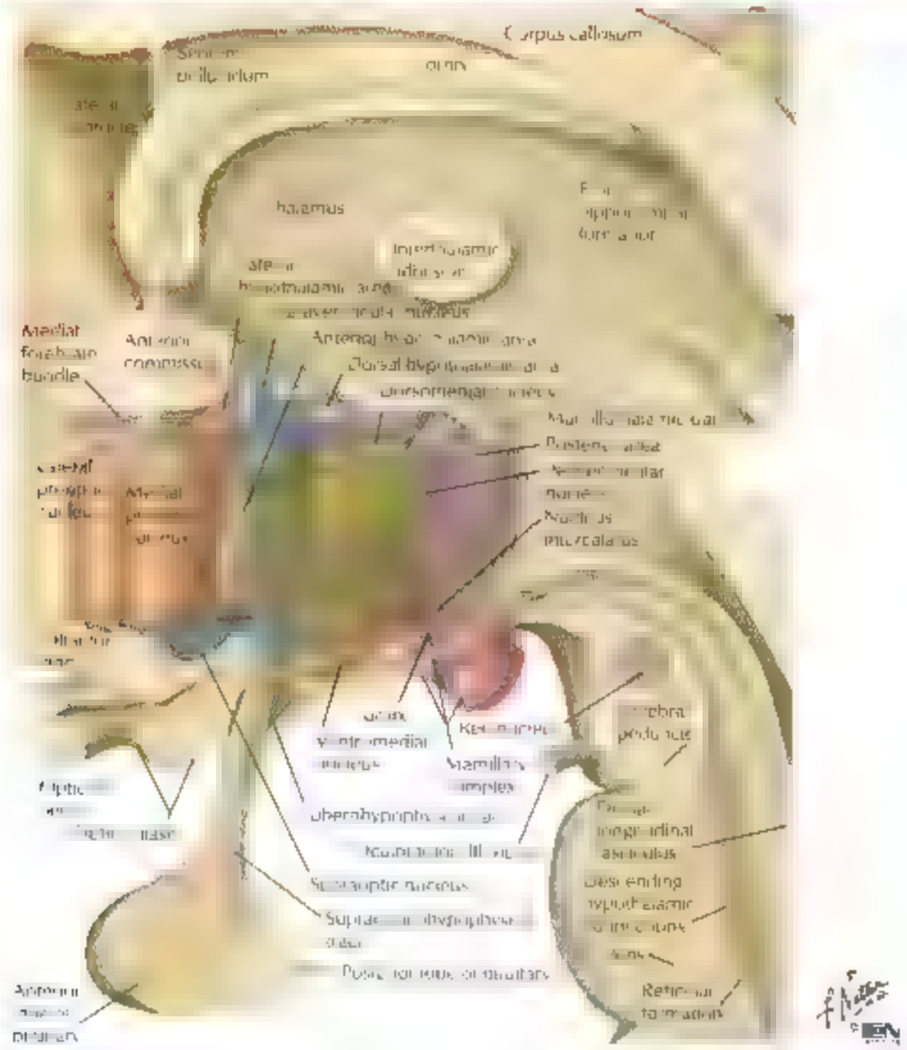


CHART 2.3 MAJOR FUNCTIONS OF THE HYPOTHALAMUS

Hypothalamic Area	Major Functions*
Preoptic and anterior	Heat loss center; activates vasodilation and sweating
Posterior	Heat conservation; activates cutaneous vasoconstriction and shivering
Lateral	Feeding center; drive behavior
Ventromedial	Satiety center; inhibits eating behavior
Supraoptic	ADH and oxytocin secretion
Paraventricular	ADH and oxytocin secretion
Periventricular	Releasing hormones for the anterior pituitary

*Not all functions are present in all species; responses vary

FIGURE 2.17 SCHEMATIC RECONSTRUCTION OF THE HYPOTHALAMUS

The hypothalamus, part of the diencephalon, controls a number of major homeostatic systems within the body. Its functions include the regulation of body temperature, water intake, and the endocrine system (see Chapter 3). Motivated behaviors, including eating behavior, receive input from the reticular formation. Sleep-wake cycle modulation by the hypothalamus is part of the limbic system, which also includes the amygdala and the medulla. Blood pressure and heart rate are also regulated by the hypothalamus. The hypothalamus integrates these inputs in relation to the functions listed.

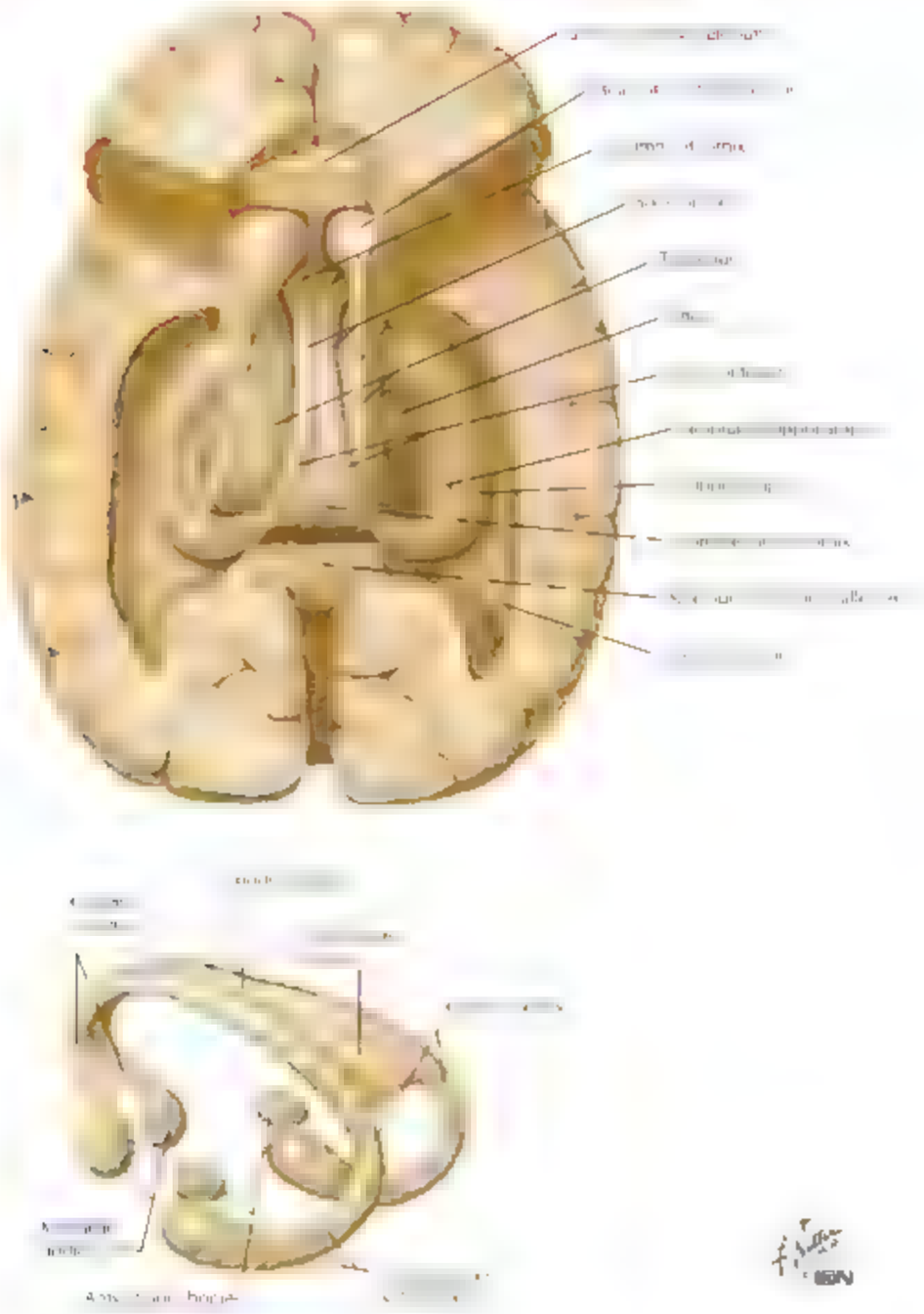


FIGURE 2.18 HIPPOCAMPUS AND FORNIX

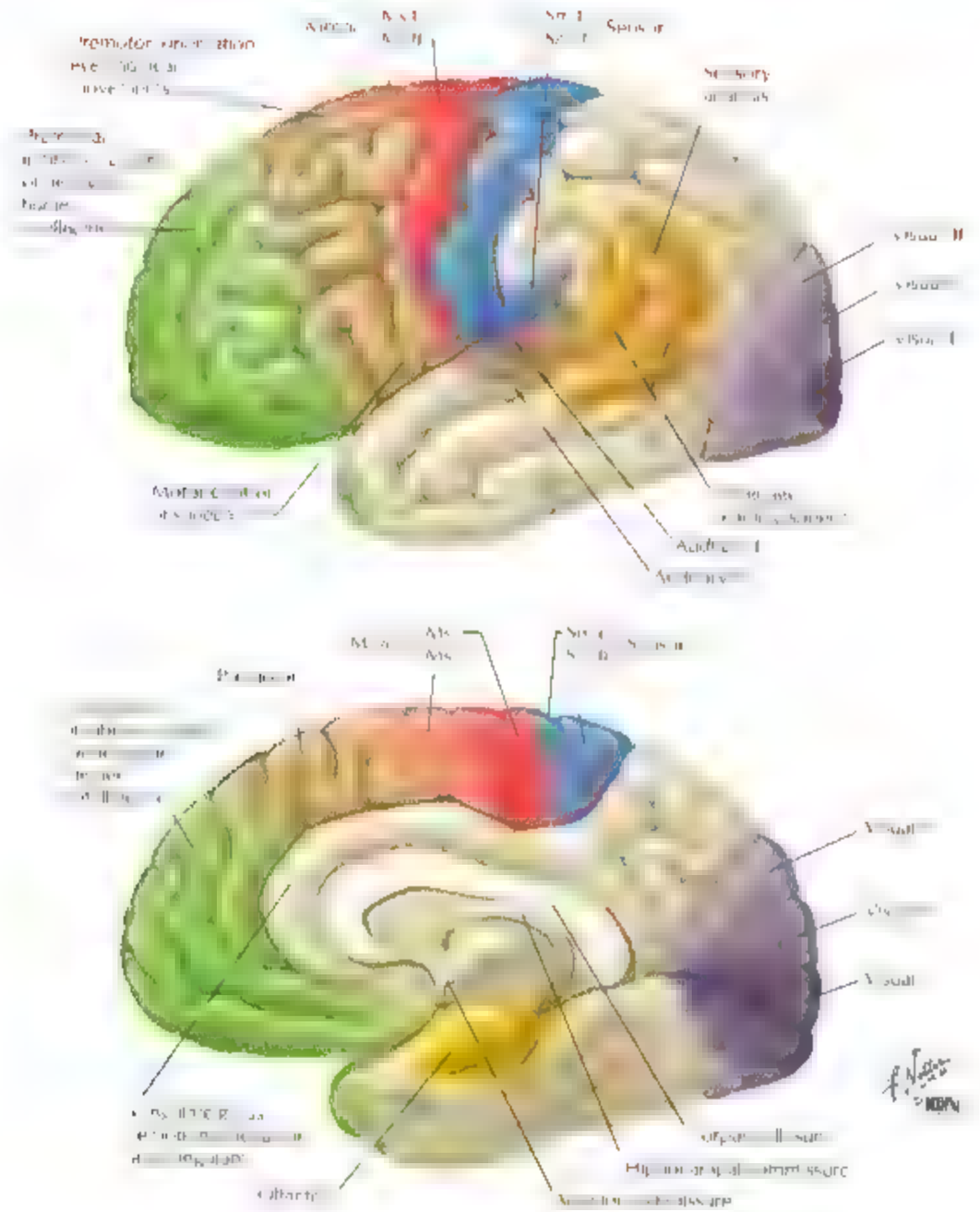


FIGURE 2.19 CEREBRAL CORTEX: LOCALIZATION OF FUNCTION AND ASSOCIATION PATHWAYS

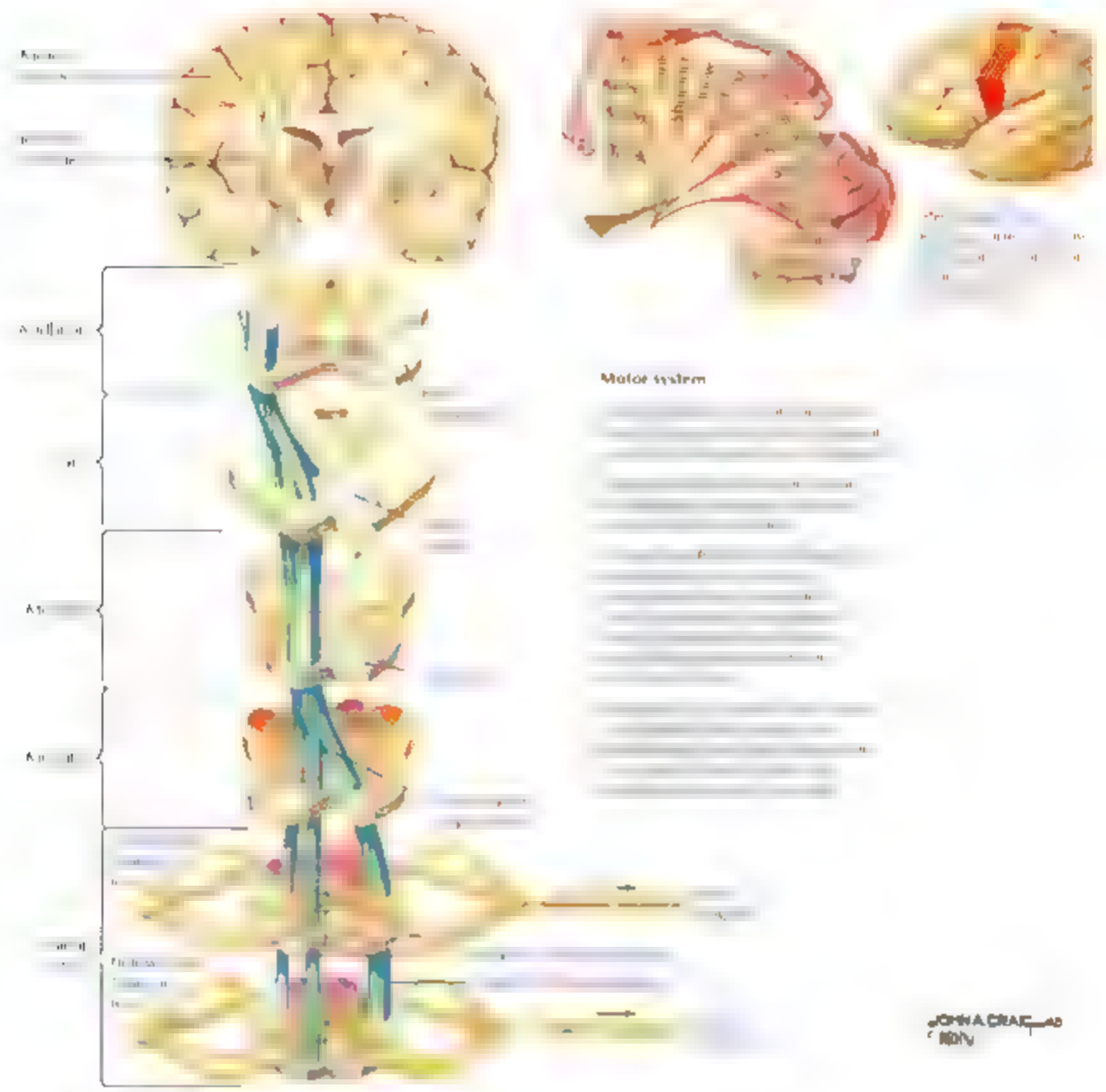


FIGURE 2.20 CORTICOSPINAL TRACTS

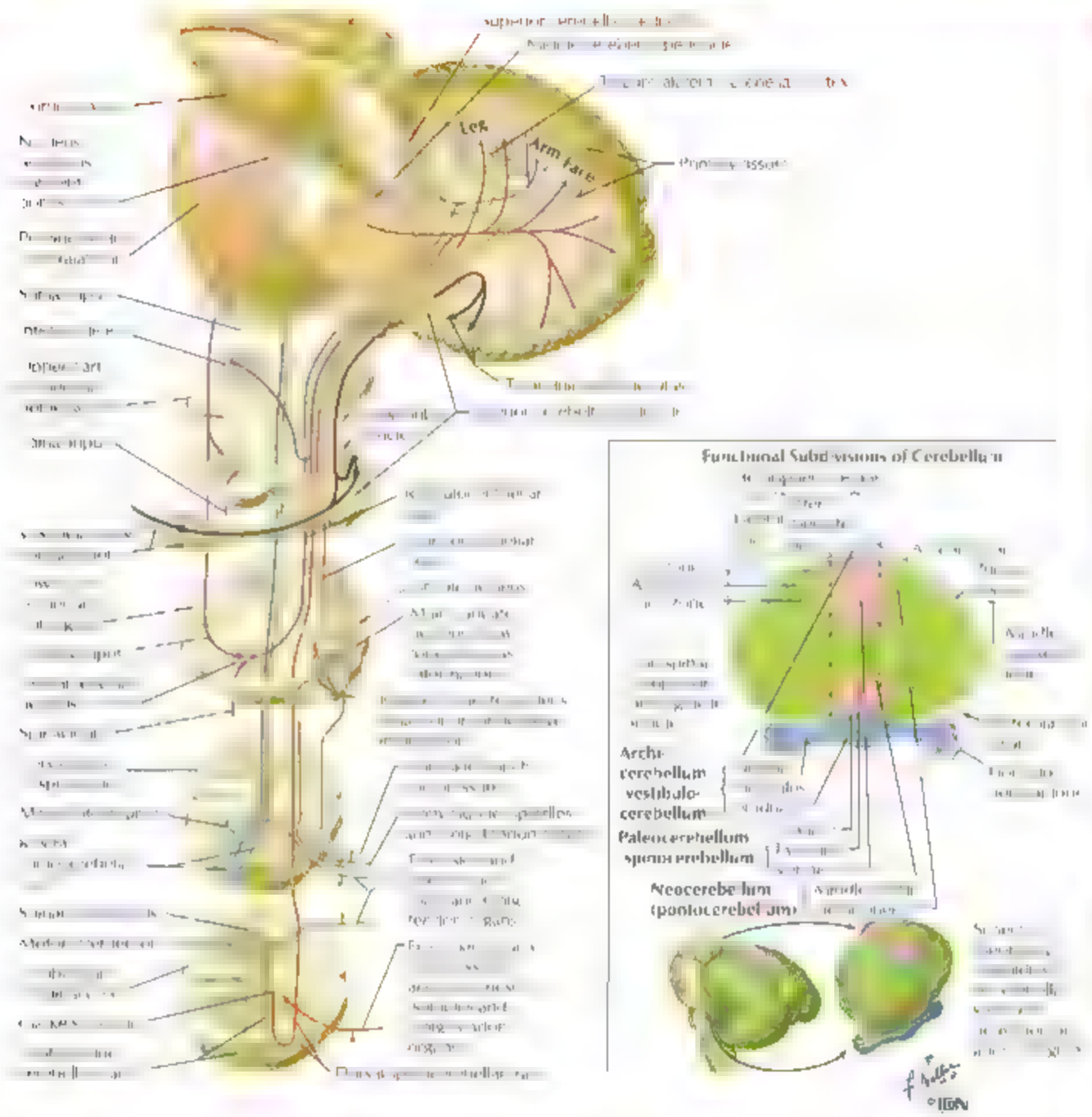


FIGURE 2.27 CEREBELLAR AFFERENT PATHWAYS

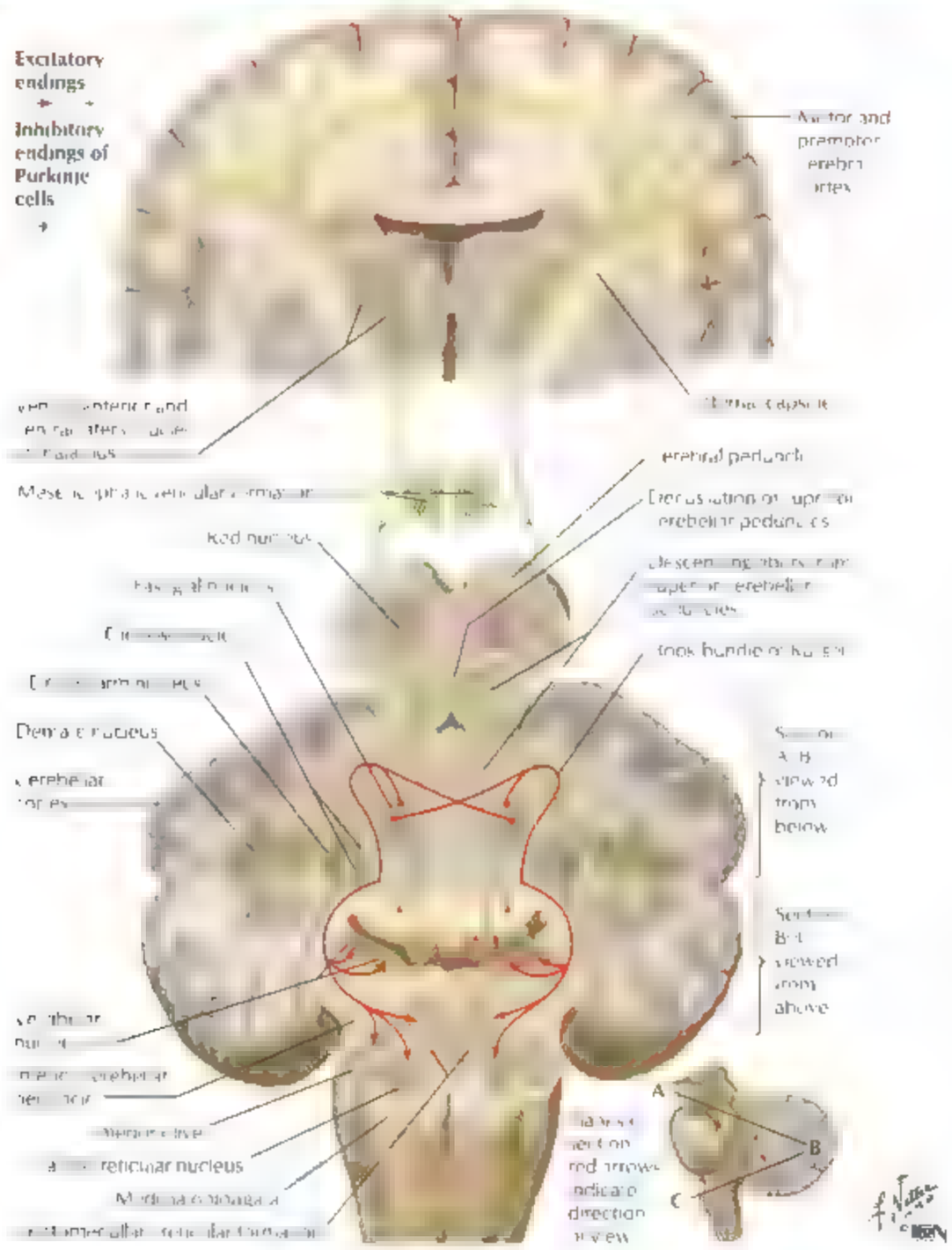


FIGURE 2.22 CEREBELLAR EFFERENT PATHWAYS

The cerebellum plays an important role in coordinating motor activity. It receives sensory information from the eyes, ears, and proprioceptors in the muscles and joints. It also receives descending motor commands from the cerebral cortex. The cerebellum compares these inputs and sends efferent fibers to the anterior descending motor pathways. The cerebellum is primarily involved in controlling posture and balance and in movements of the head, eyes, and limbs. It helps to plan movements that require precise timing and coordination, such as movements of the arms and hands to pick up objects.

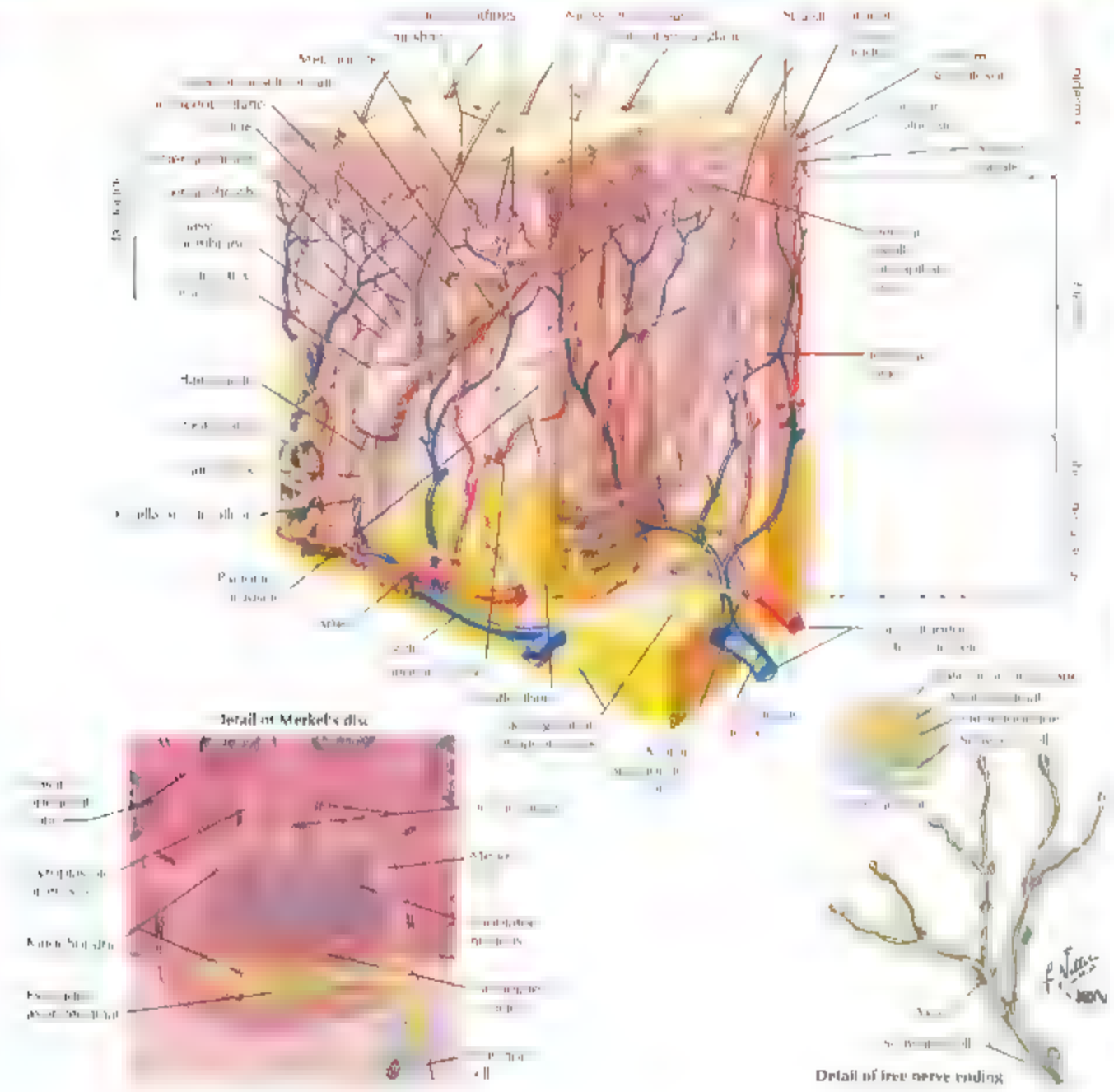


FIGURE 2-23 Skin and Cutaneous Receptors

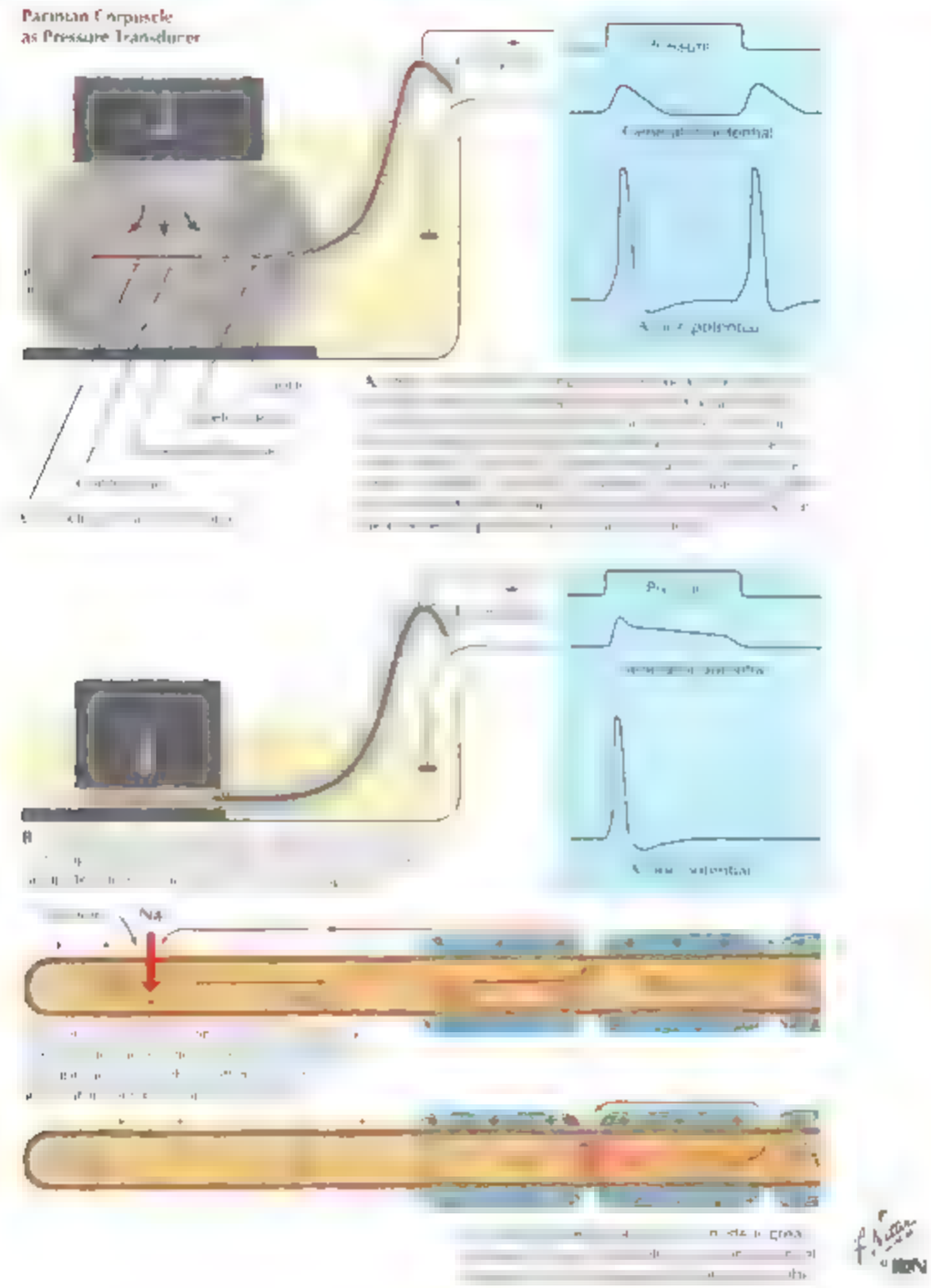


FIGURE 2.24 PACINIAN CORPUSCLE

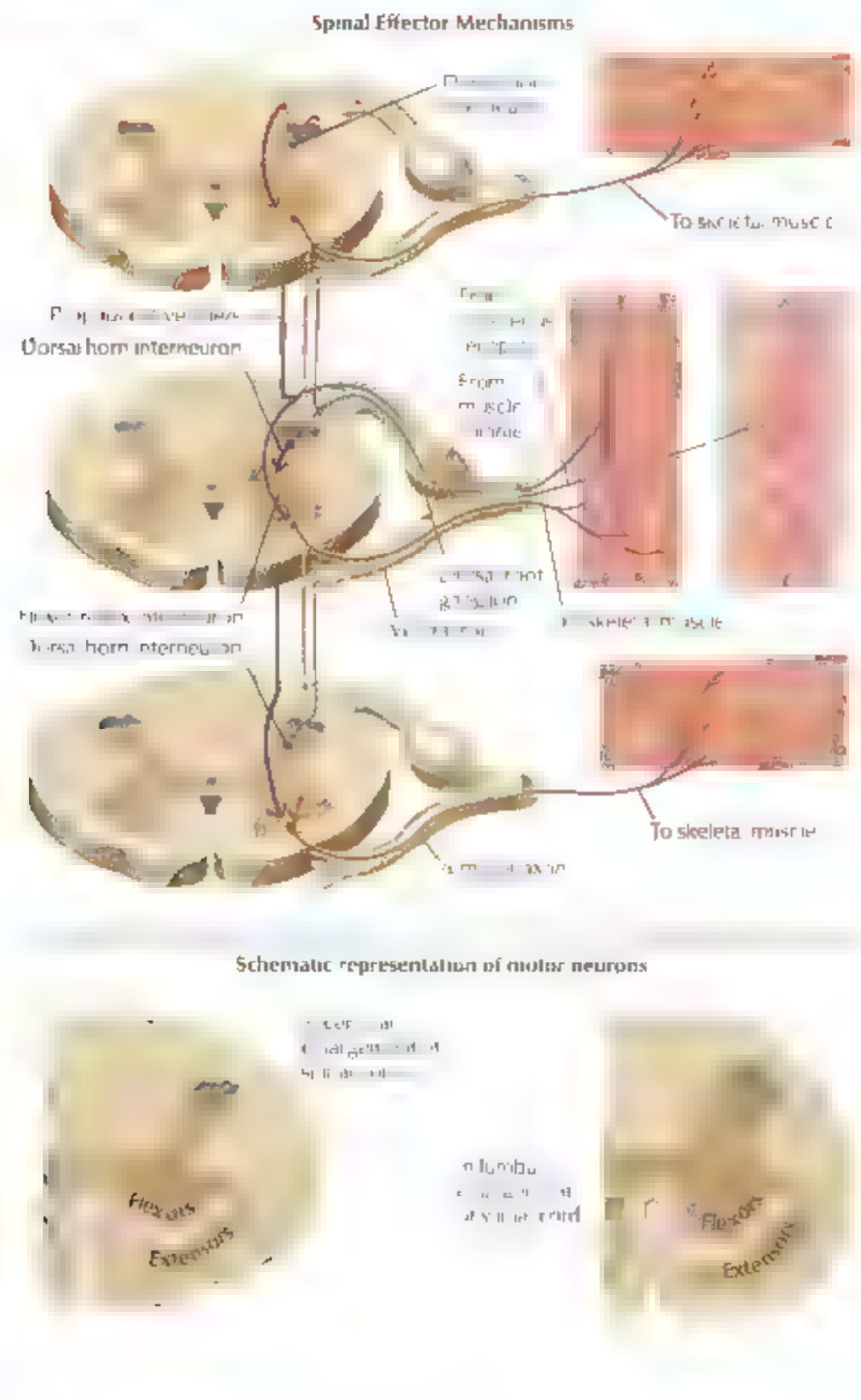


FIGURE 2.25 PROPRIOCEPTION: SPINAL EFFECTOR MECHANISM

Position sense or proprioception involves input from cutaneous [illegible] figure of upper panel. Both monosynaptic reflex pathways (middle figure of upper panel) and polysynaptic pathways involving several spinal cord segments (top and bottom figures of upper panel) initiate muscle contraction reflexes. The lower panel shows the motor neuron pools of bodies in the ventral horn of the spinal cord that innervate limb muscles (flexor and extensor muscles of upper and lower limbs).

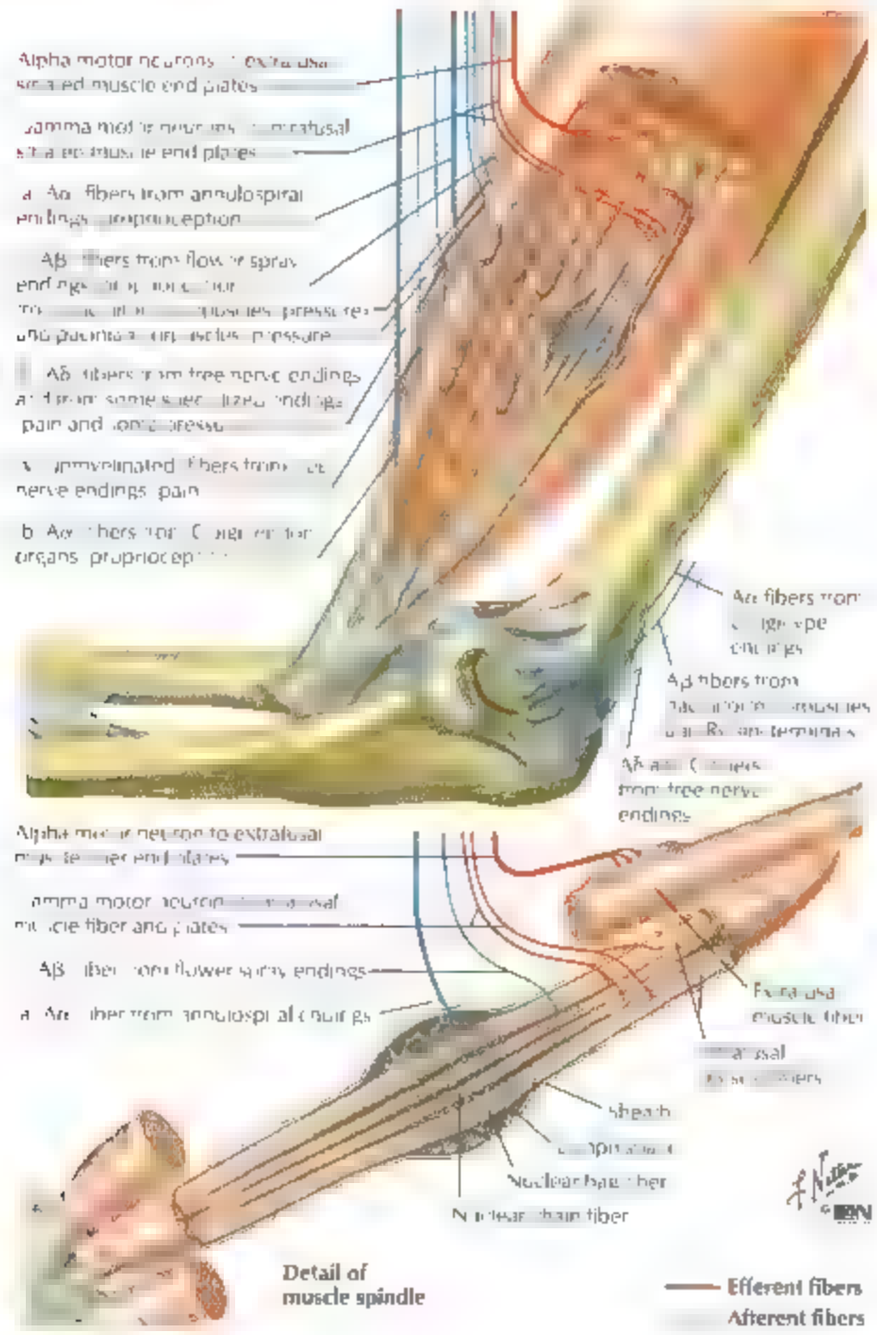


FIGURE 2-26 MUSCLE AND JOINT RECEPTORS

Muscle spindles and Golgi tendon organs send afferent signals to the brain that convey the position of limbs and help coordinate muscle movement. Muscle spindles convey information on muscle tension and on rate of change (dynamic forces) and muscle length (static forces). The nuclear bag fibers respond to both dynamic and static forces, whereas the nuclear chain fibers respond to static forces. Gamma motor neurons adjust the appropriate tension on the nuclear bag and nuclear chain fibers when the muscle contracts. Golgi tendon organs, located at the junction of muscle and tendon, are activated when the muscle contracts and help regulate the force of muscle contraction.

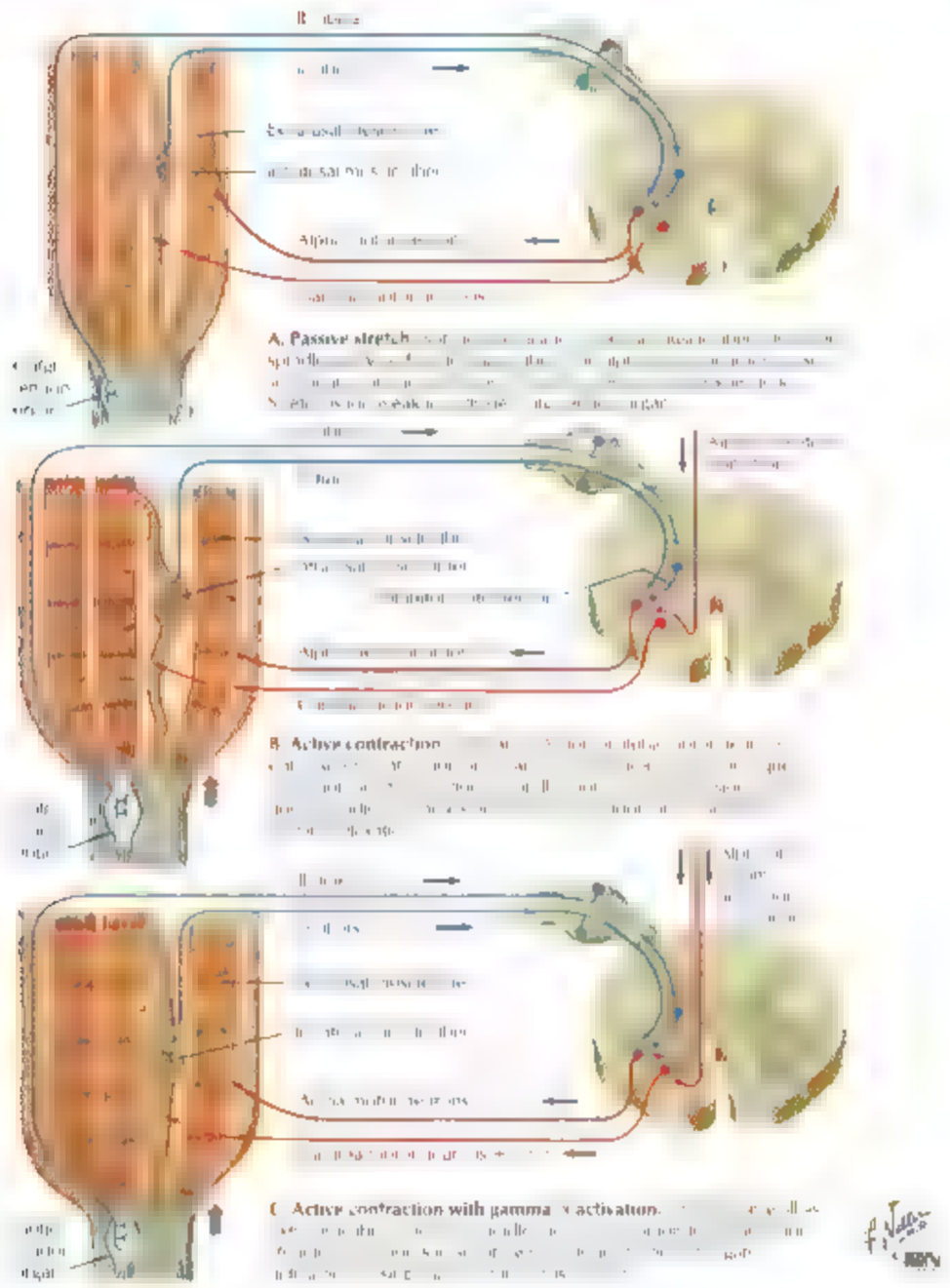


FIGURE 2.27 PROPRIOCEPTIVE REFLEX CONTROL OF MUSCLE TENSION

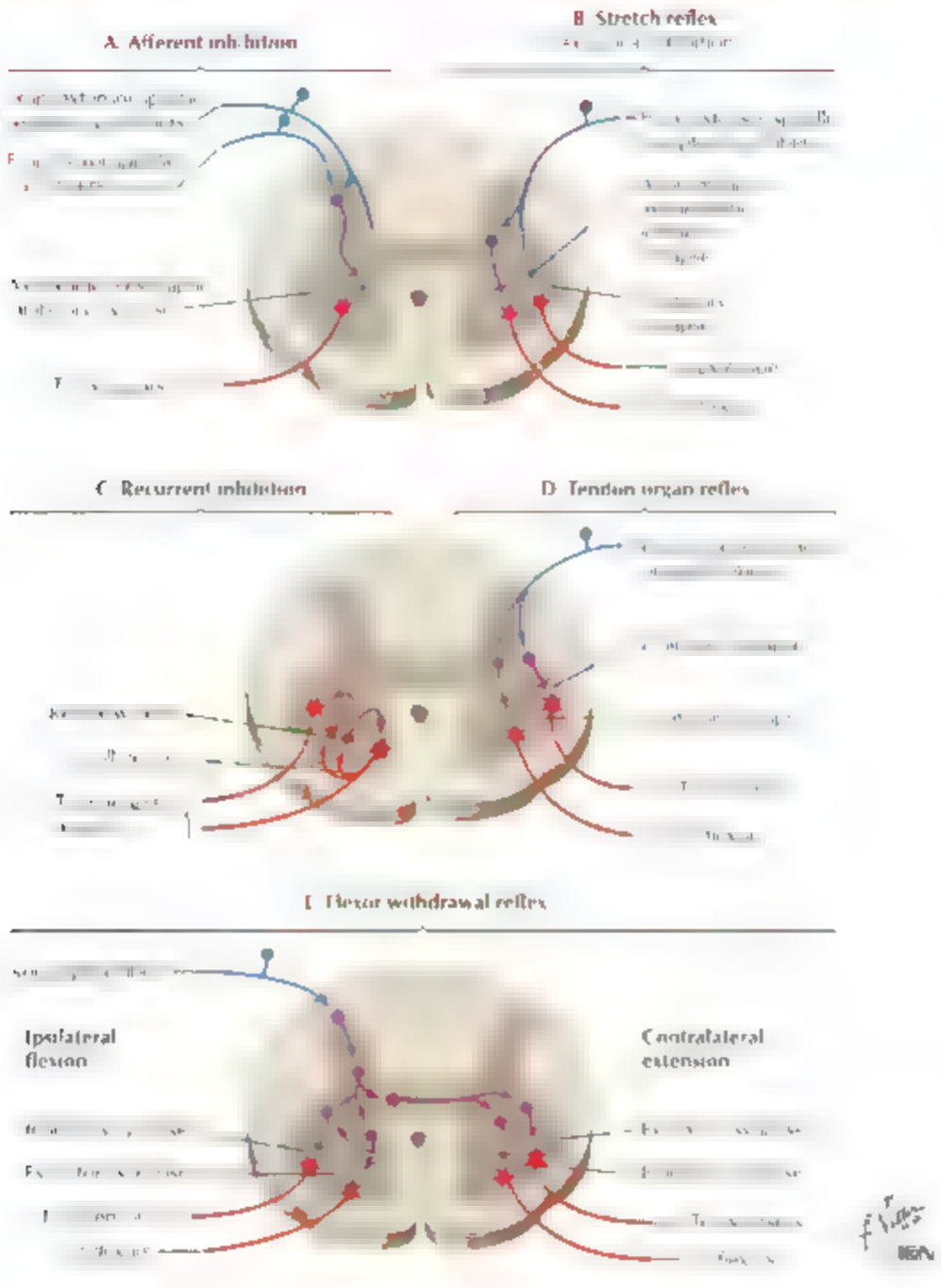


FIGURE 2.28 SPINAL REFLEX PATHWAYS

Summary of the spinal reflex pathways.

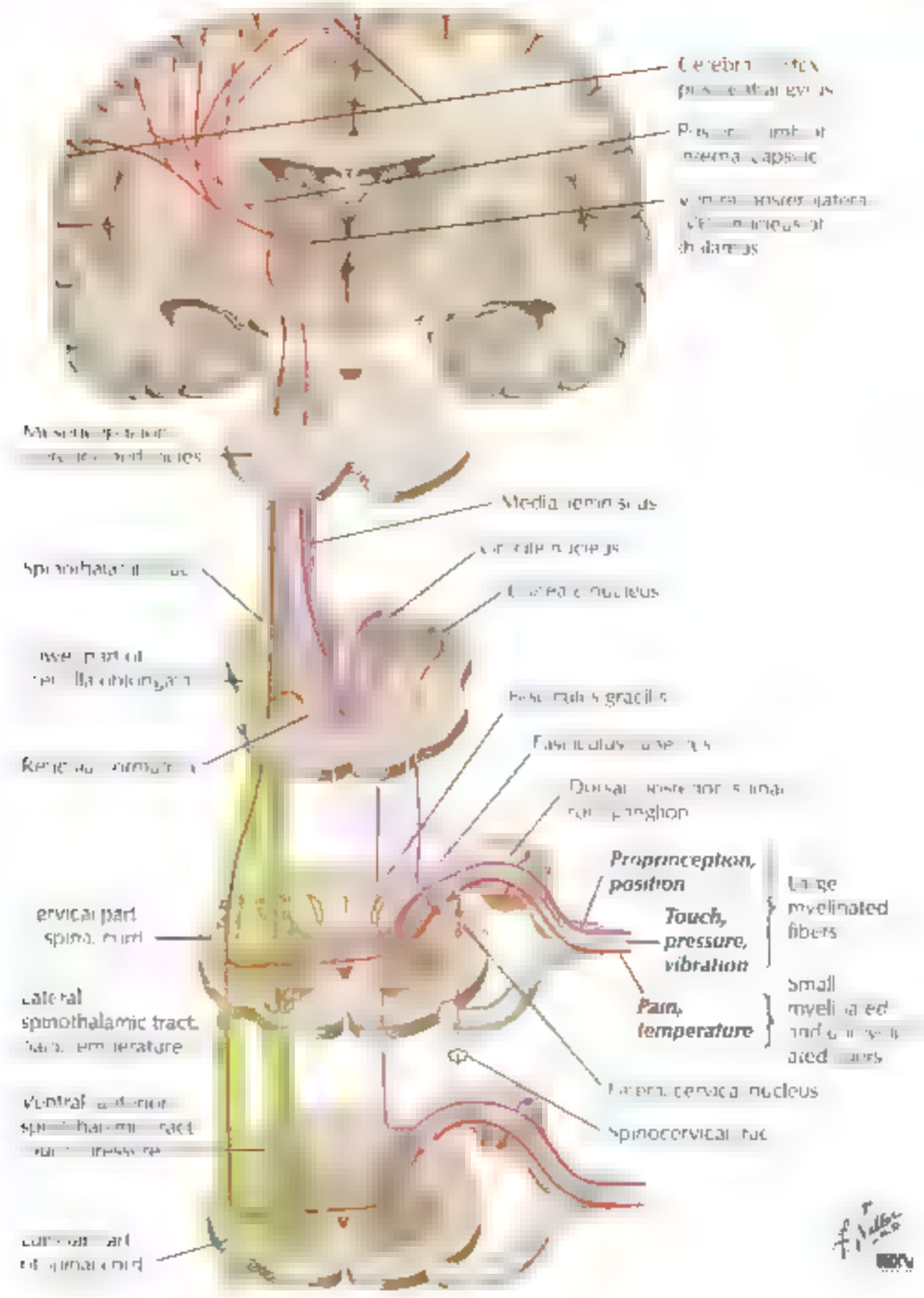


FIGURE 2.29 SOMESTHETIC SYSTEM OF THE BODY

Pain, temperature, and crude pressure sensations are transmitted mainly by the anterolateral system (spinothalamic tract) to the thalamus and then to the primary somatosensory cortex (postcentral gyrus). The discriminative aspects of touch are carried by the dorsal column–medial lemniscal system (fasciculus gracilis and fasciculus cuneatus). This system conveys proprioceptive, vibratory, and discriminative sensations to the thalamus. Several intermediate neurons are interposed between the primary sensory neurons and the thalamus. Some of these intermediate neurons, whereas the lateral spinothalamic system relates somatic sensations to the entire body and primitive sensations. Blue and purple lines show the two major pathways. Both pathways cross to the opposite side and ascend to the thalamus as parallel pathways. At the thalamus synapse with neurons that project to the cortex.

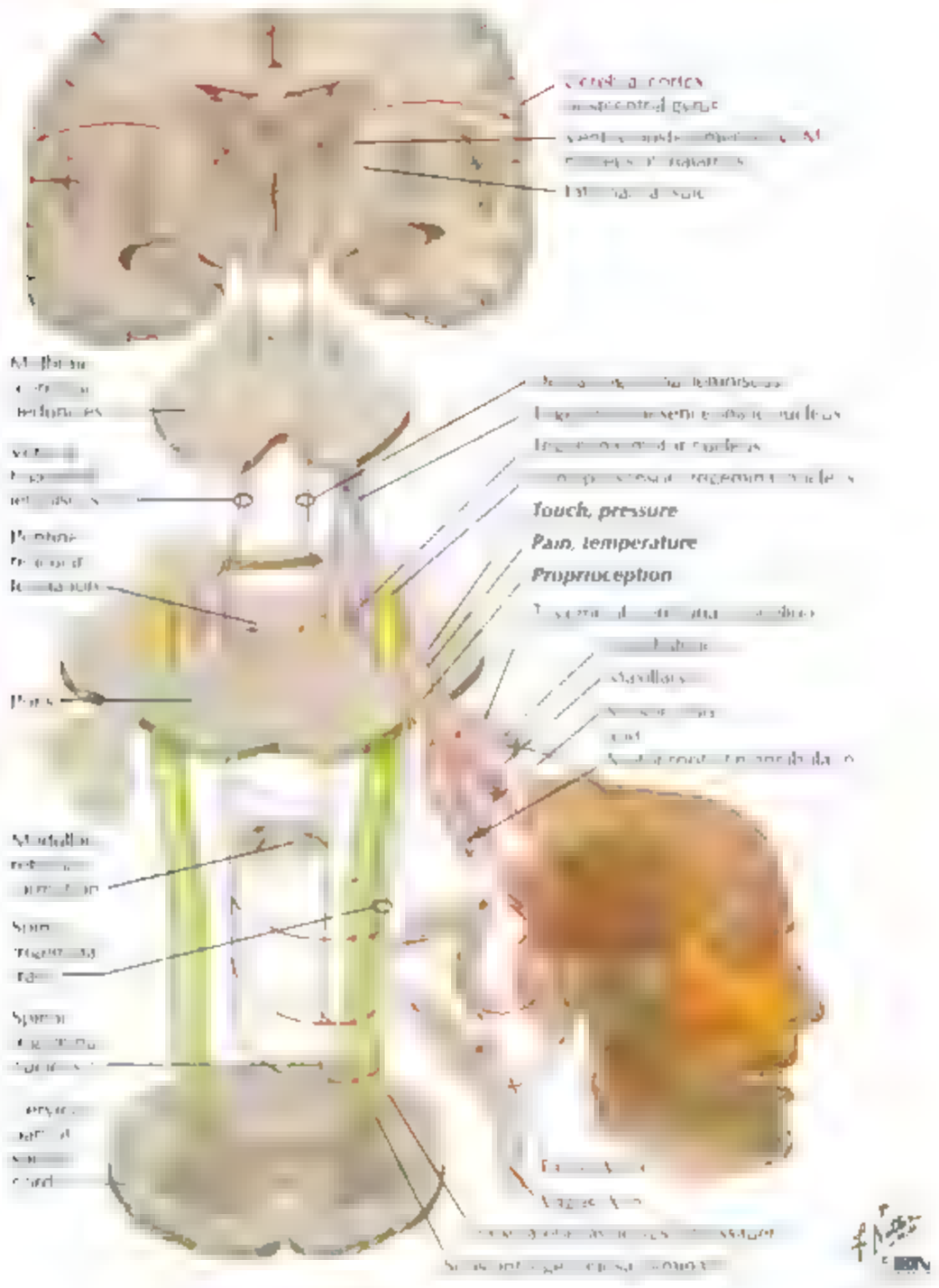


FIGURE 2.30 SOMESTHETIC SYSTEM OF THE HEAD

Nerve cells bodies [illegible] touch, pressure [illegible] the upper [illegible] the head are in the trigeminal ganglion on the root of CN V, nerve that enters the pons at right. Nerve cell bodies mediating proprioception [illegible] the mesencephalic nucleus of CN V [illegible] purple dots. Most pain neurons project to the contralateral VPM nucleus of the thalamus [illegible] ventral extragyrus of the [illegible] where the area is [illegible] represented.

Levels of principal dermatomes

C5	[illegible]
C5, 6, 7	[illegible]
C8, T1	[illegible]
C6	[illegible]
C6, 7, 8	[illegible]
C8	[illegible]
T4	[illegible]
T10	[illegible]
T12	[illegible]
L1, 2, 3, 4	[illegible]
L4, 5, S1	[illegible]
L4	[illegible]
S1, 2, L5	[illegible]
S1	[illegible]
S2, 3, 4	[illegible]

FIGURE 2.31 DERMATOMES

[illegible] called a [illegible]. This figure shows the [illegible] key dermatomes [illegible]

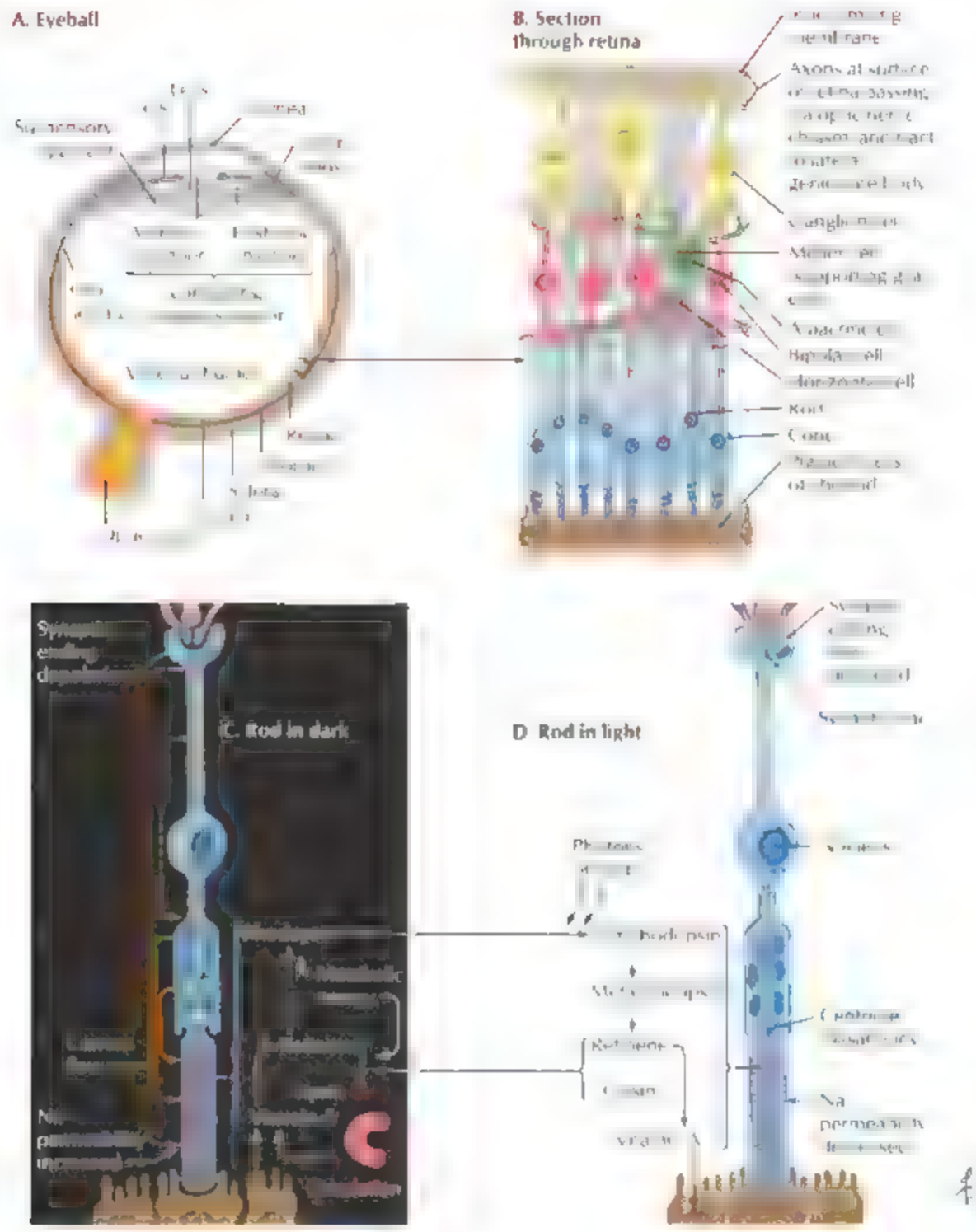


FIGURE 2.32 VISUAL RECEPTORS

The rods and cones of the retina transduce [illegible] nals. As illustrated in the rod, light is absorbed by [illegible] through a second messenger (cGMP) [illegible] the membrane [illegible] the cell depolarized [illegible] hyperpolarized in the light. This is opposite to the response to light of most other receptors, in which the response to a stimulus results in depolarization of the receptor membrane.

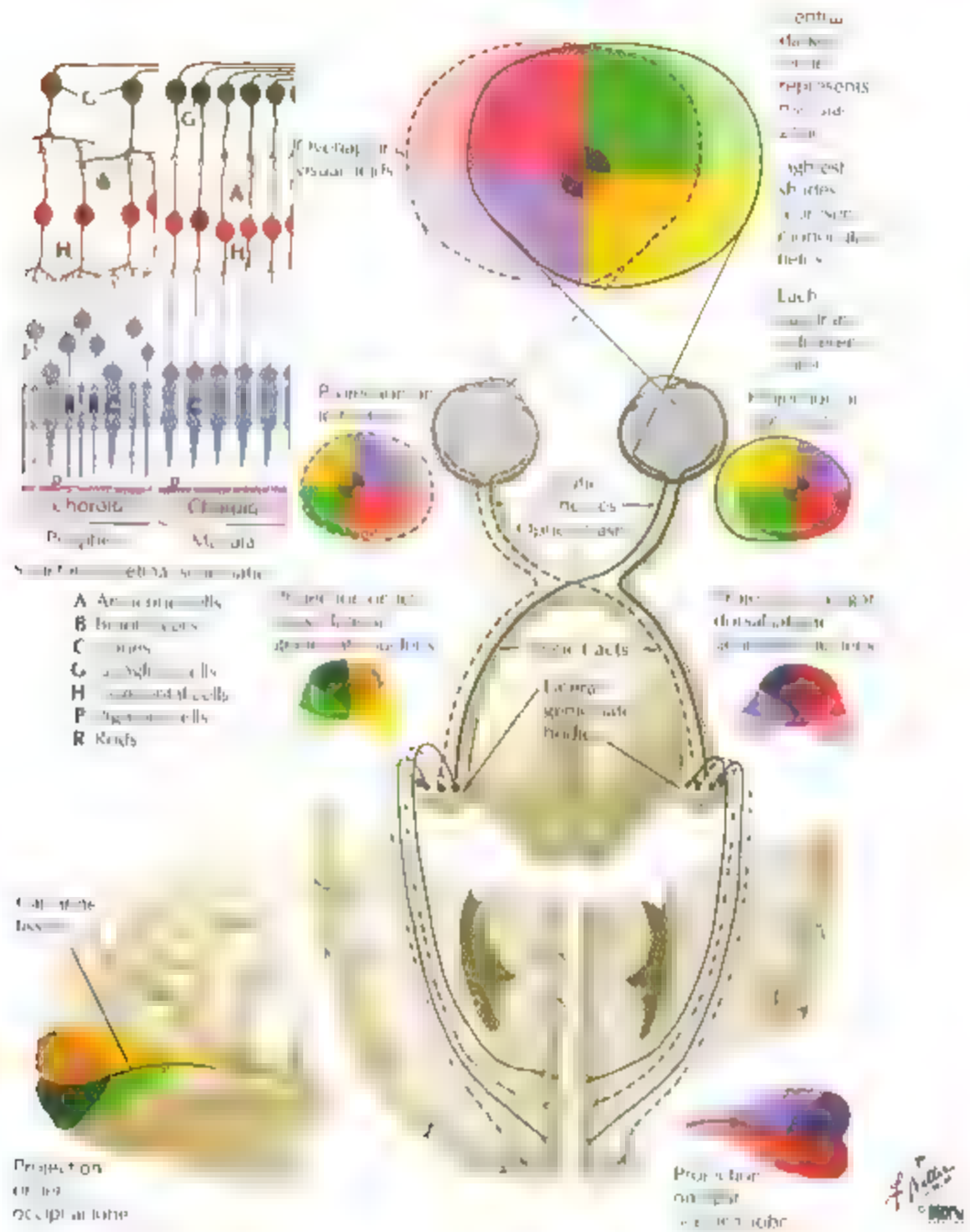


FIGURE 2.33 RETINOGENICULOSTRIATE VISUAL PATHWAY

The retina has two kinds of photoreceptors: cones that mediate color vision and rods that mediate light perception at low levels. The greatest density of cones and the region of the most acute vision is the fovea centralis. In the rest of the retina, where only cones are found and the resolution of visual scenes is poor, the photoreceptors are enveloped by ganglion cells whose axons course in the optic nerves. Visual signals from the nasal retina cross in the optic chiasm, while information from the temporal retina remains on the same side. The lateral geniculate body has six layers of cell bodies that receive signals from the eyes. Nerve fibers from the lateral geniculate body project to the visual cortex on the medial surface of the occipital lobe.

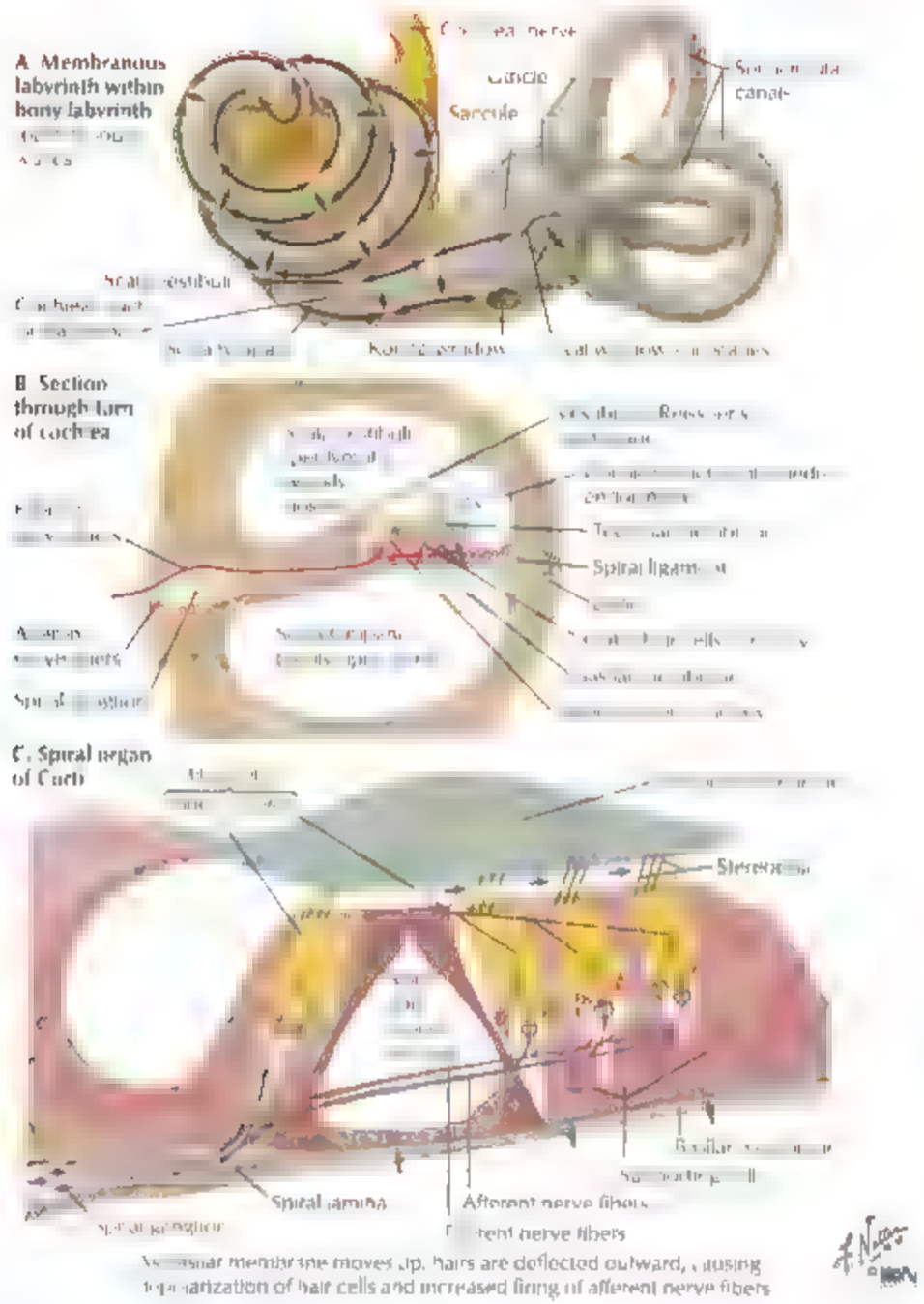


FIGURE 2.34 COCHLEAR RECEPTORS

ished by the hair cells, which depolarize in response to vibration of

sponse to vibrations of the tympanic membrane

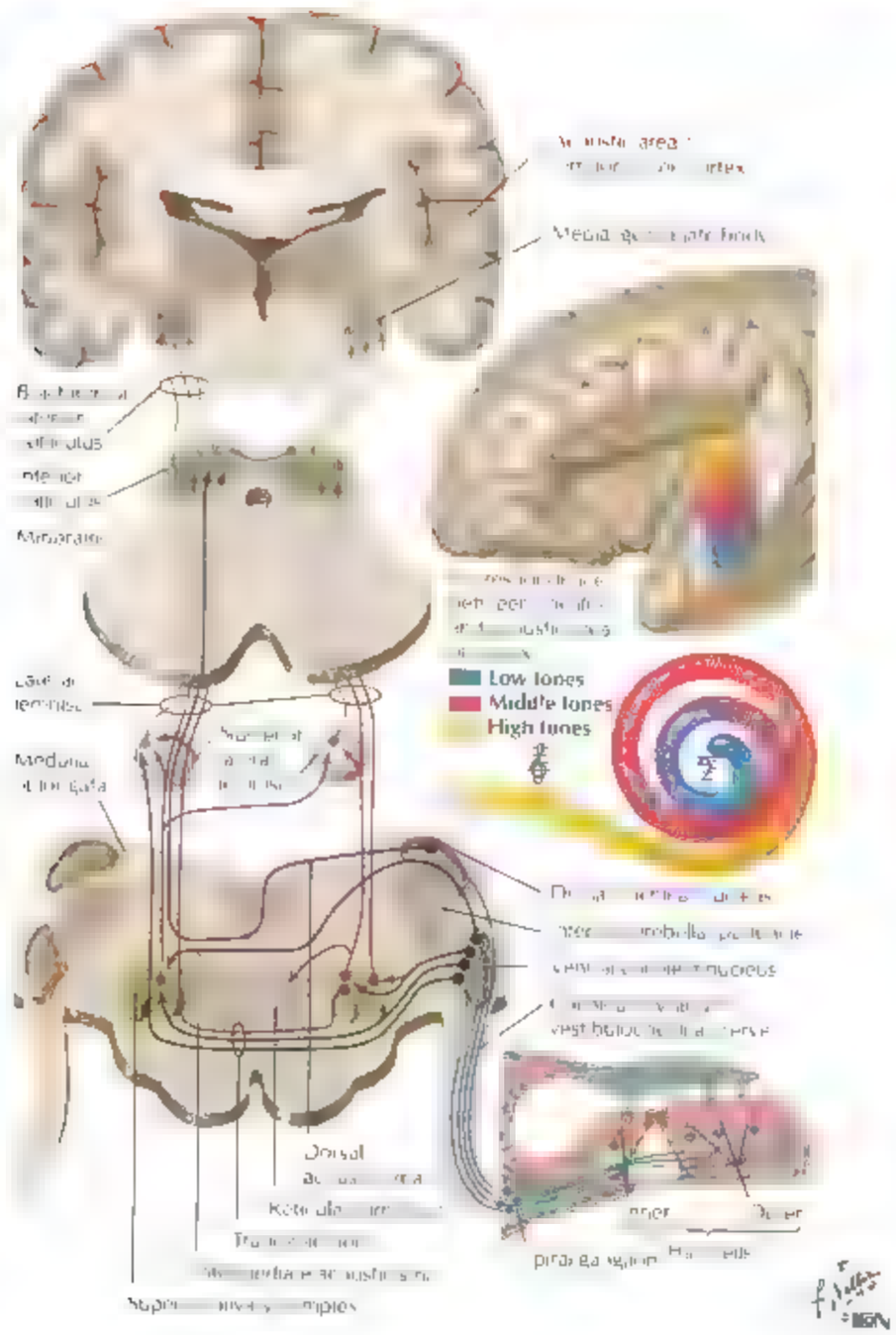


FIGURE 2.35 AUDITORY PATHWAYS

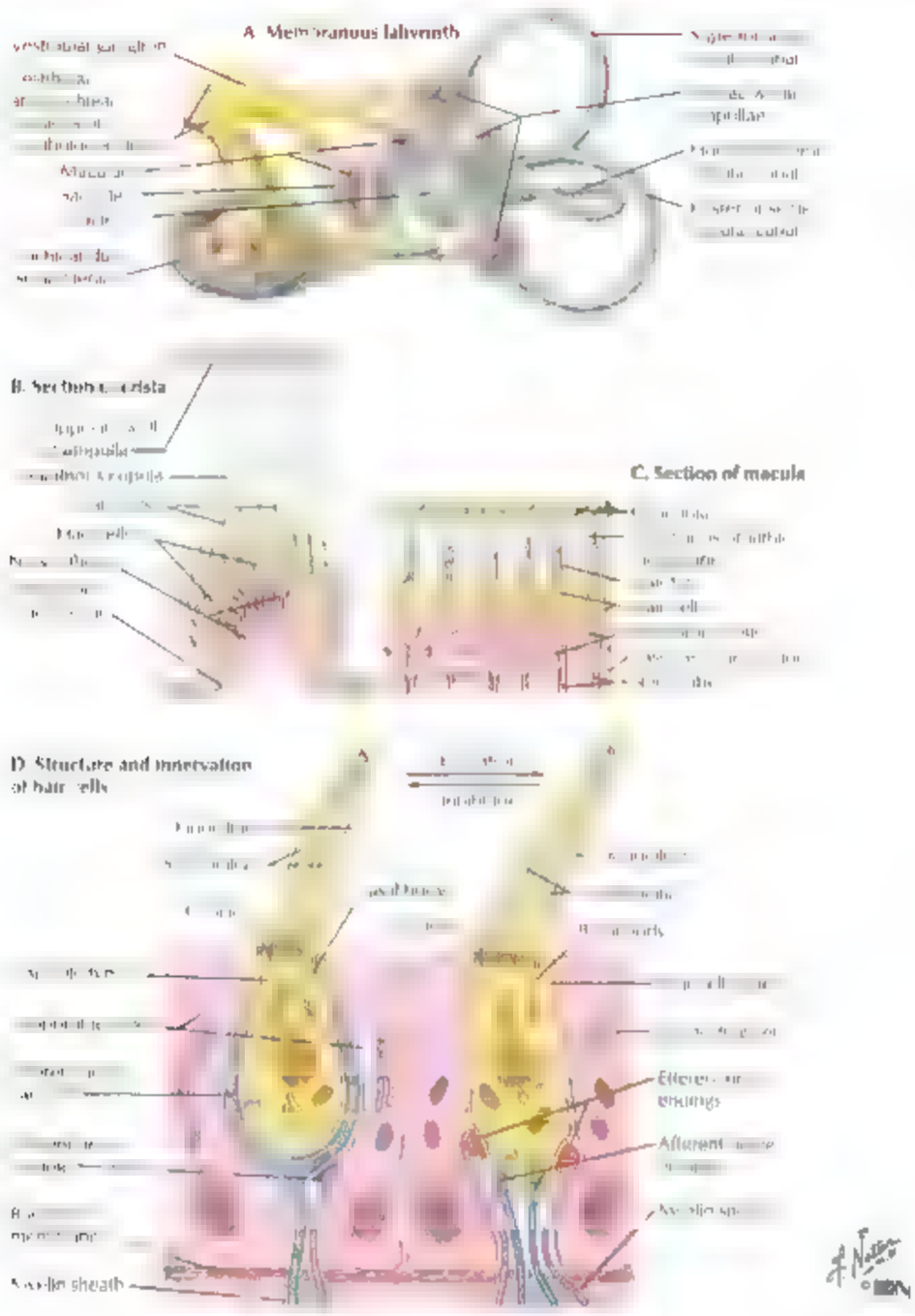


FIGURE 2-36 VESTIBULAR RECEPTORS

The vestibular apparatus detects [illegible] The utricle and saccule respond to linear acceleration, such as [illegible] This information is [illegible] panel A; higher power view of the crista is shown in panel

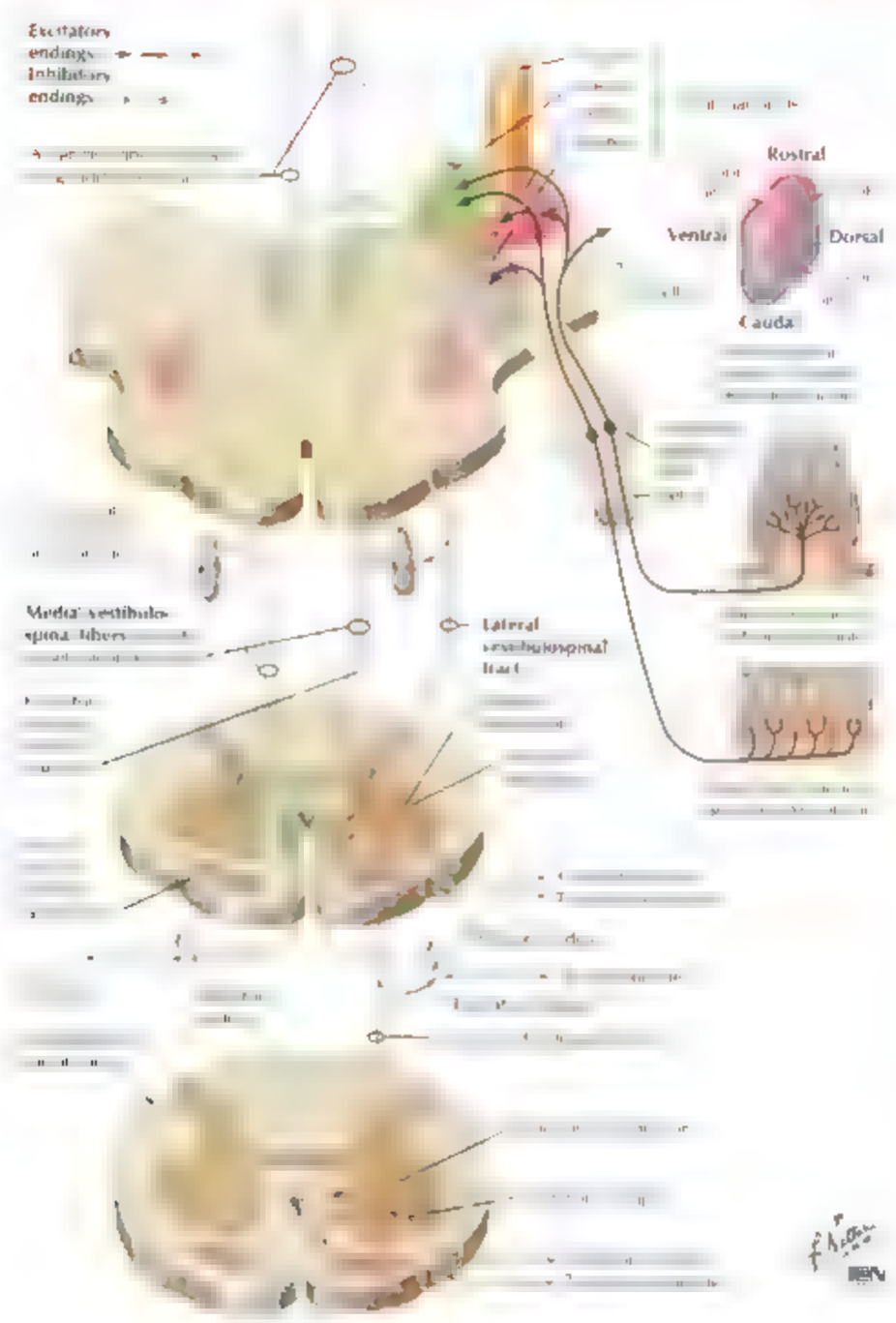


FIGURE 2.37 VESTIBULOSPINAL TRACTS

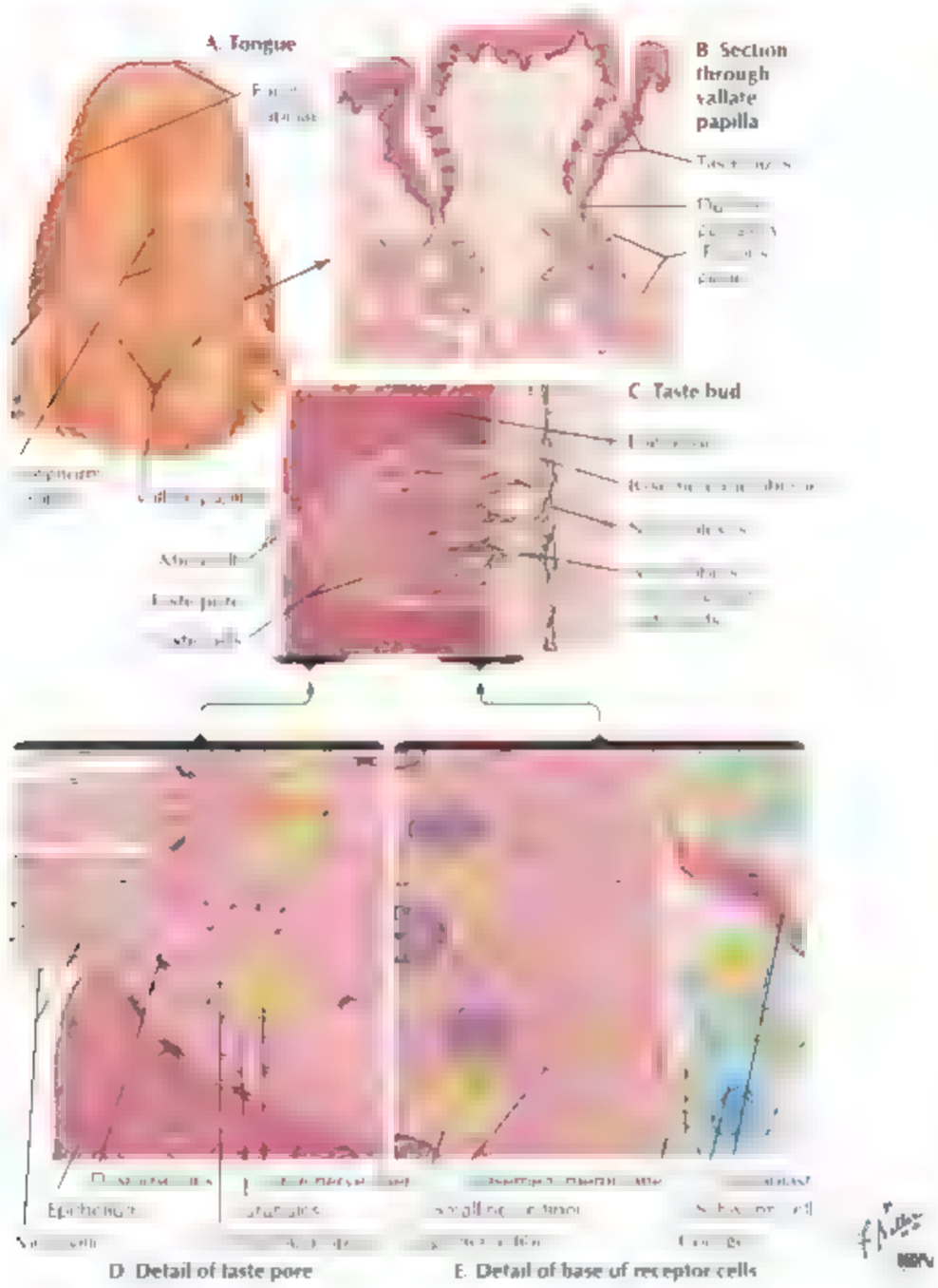


FIGURE 2.38 TASTE RECEPTORS

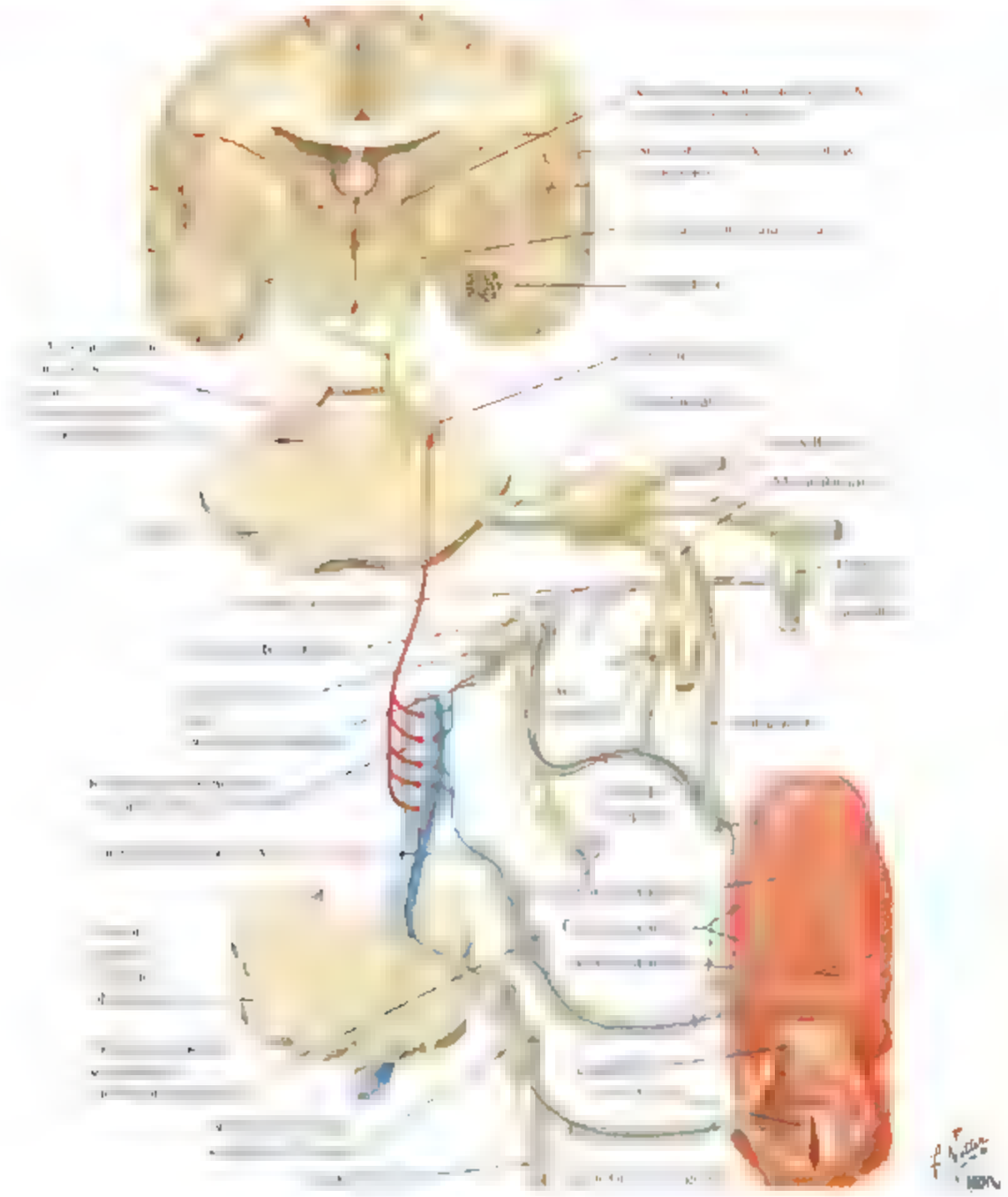


FIGURE 2-39 TASTE PATHWAYS

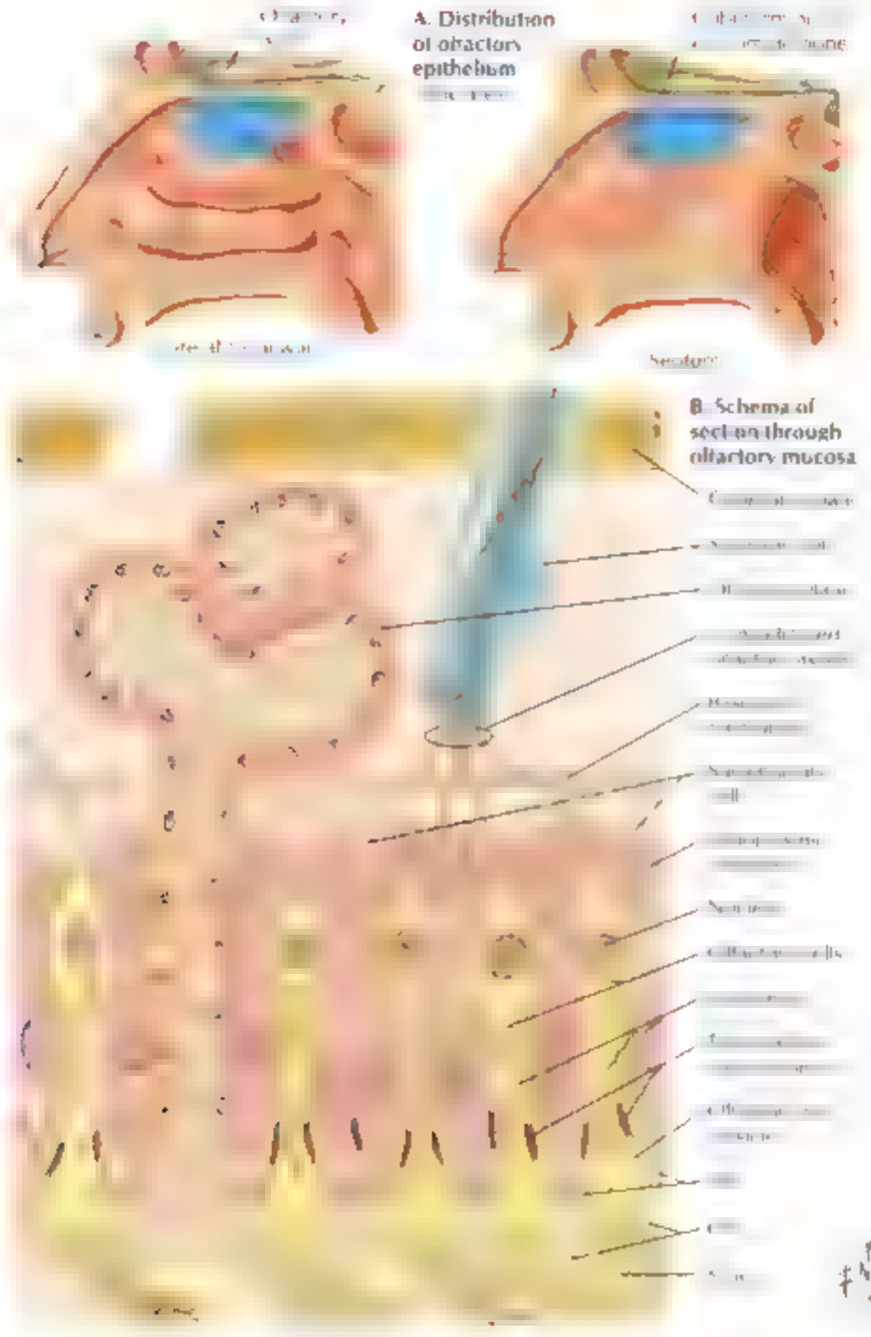


FIGURE 2.40 OLFACTORY RECEPTORS

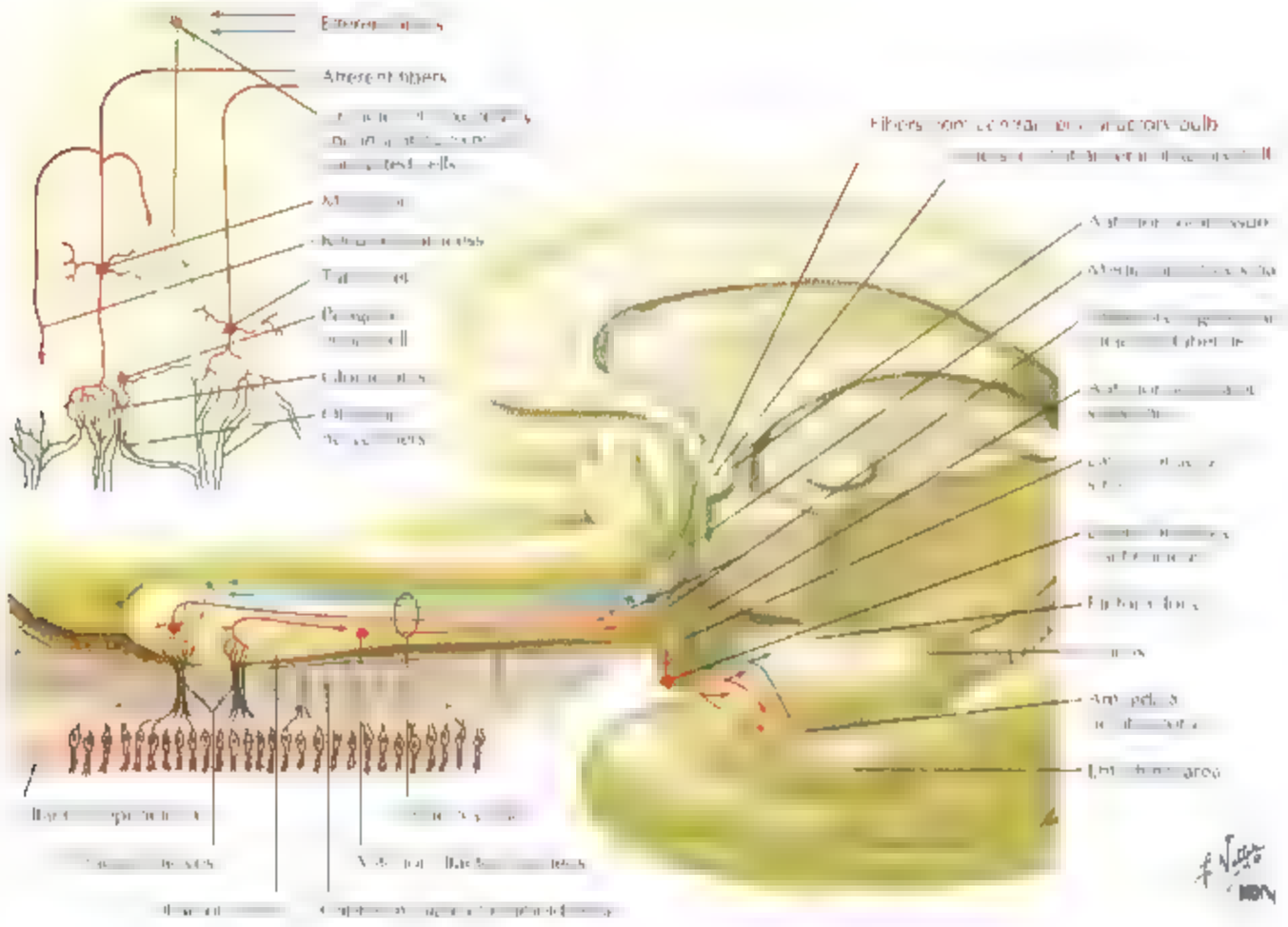


FIGURE 2.41 OLFACTORY PATHWAY

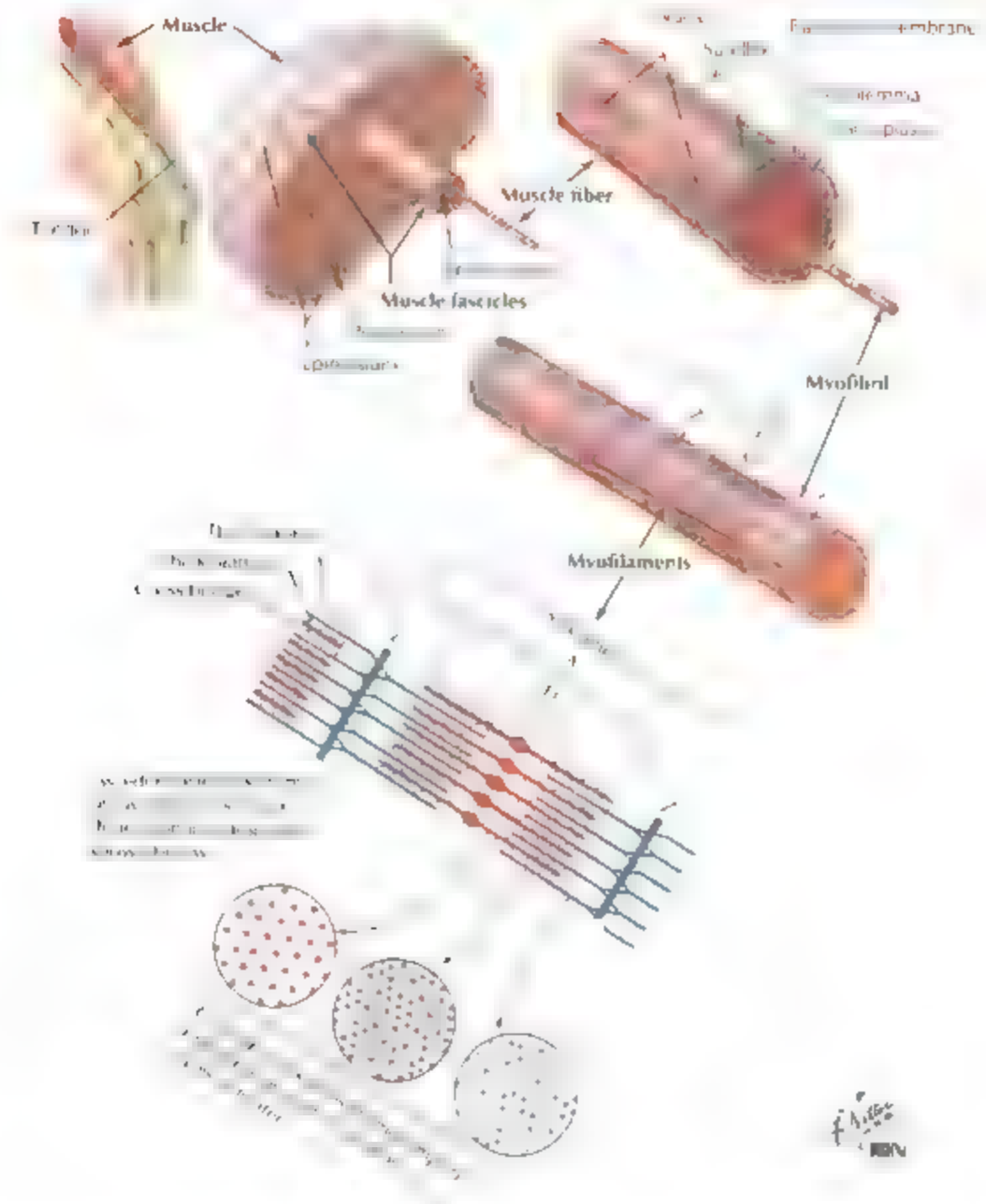


FIGURE 3.1 ORGANIZATION OF SKELETAL MUSCLE

Segment of muscle fiber greatly enlarged to show sarcoplasmic structures and inclusions

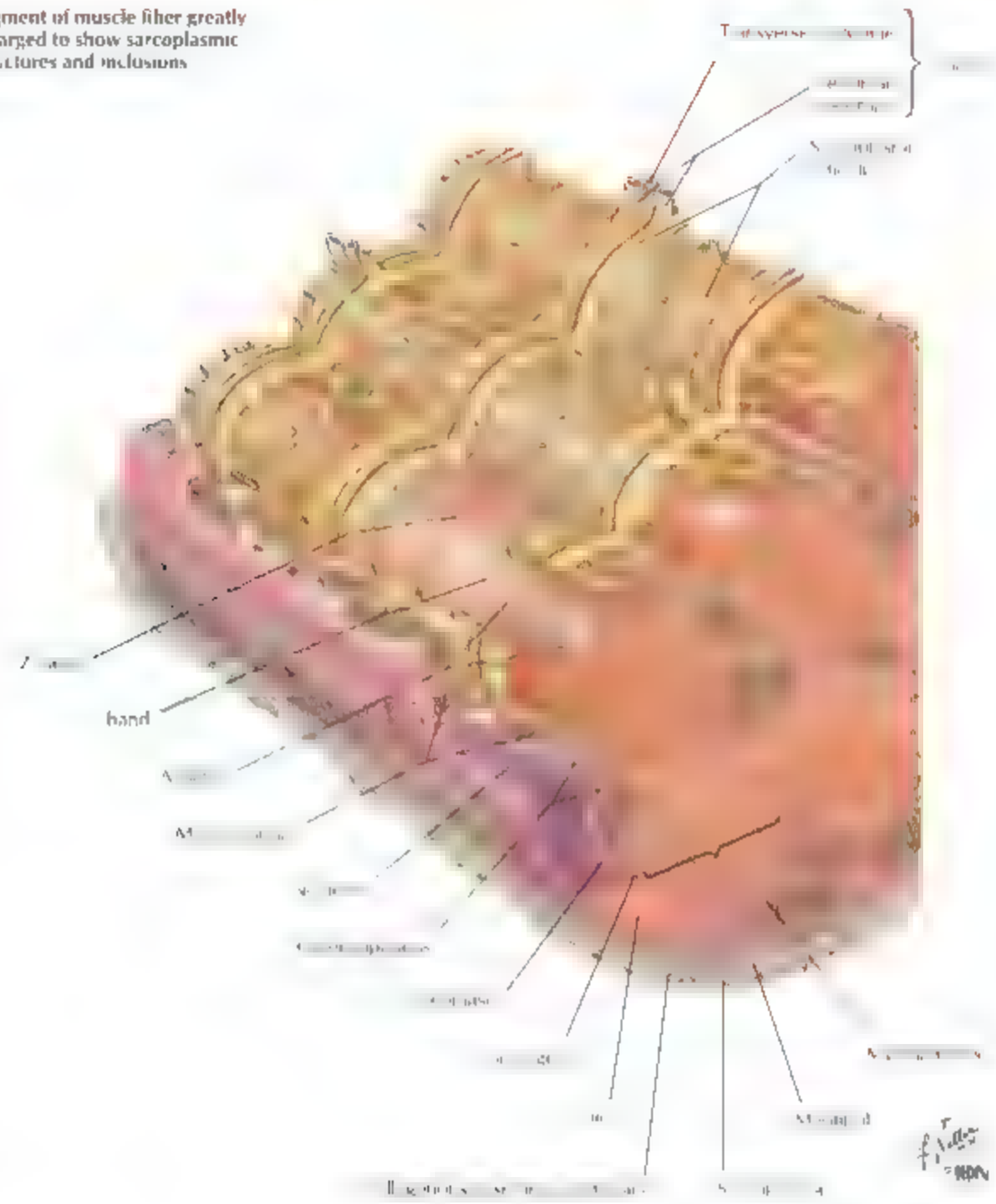


FIGURE 3.2 SARCOPLASMIC RETICULUM

The sarcoplasmic reticulum forms an elaborate network within the cell and serves as storage area for intracellular Ca^{2+}. The sarcoplasmic reticulum surrounds the myofibrils. A portion of the sarcoplasmic reticulum, called the terminal cisterna, is filled with a Ca^{2+}-binding protein called calsequestrin. Transverse tubules (T tubules) are tubular invaginations of the sarcolemma that penetrate into the center of the muscle fiber. Each T tubule is associated with two terminal cisternae of the sarcoplasmic reticulum. Depolarization of the muscle sarcolemma travels down the T tubules and causes the release of Ca^{2+} from the sarcoplasmic reticulum. See Figure 3.3.

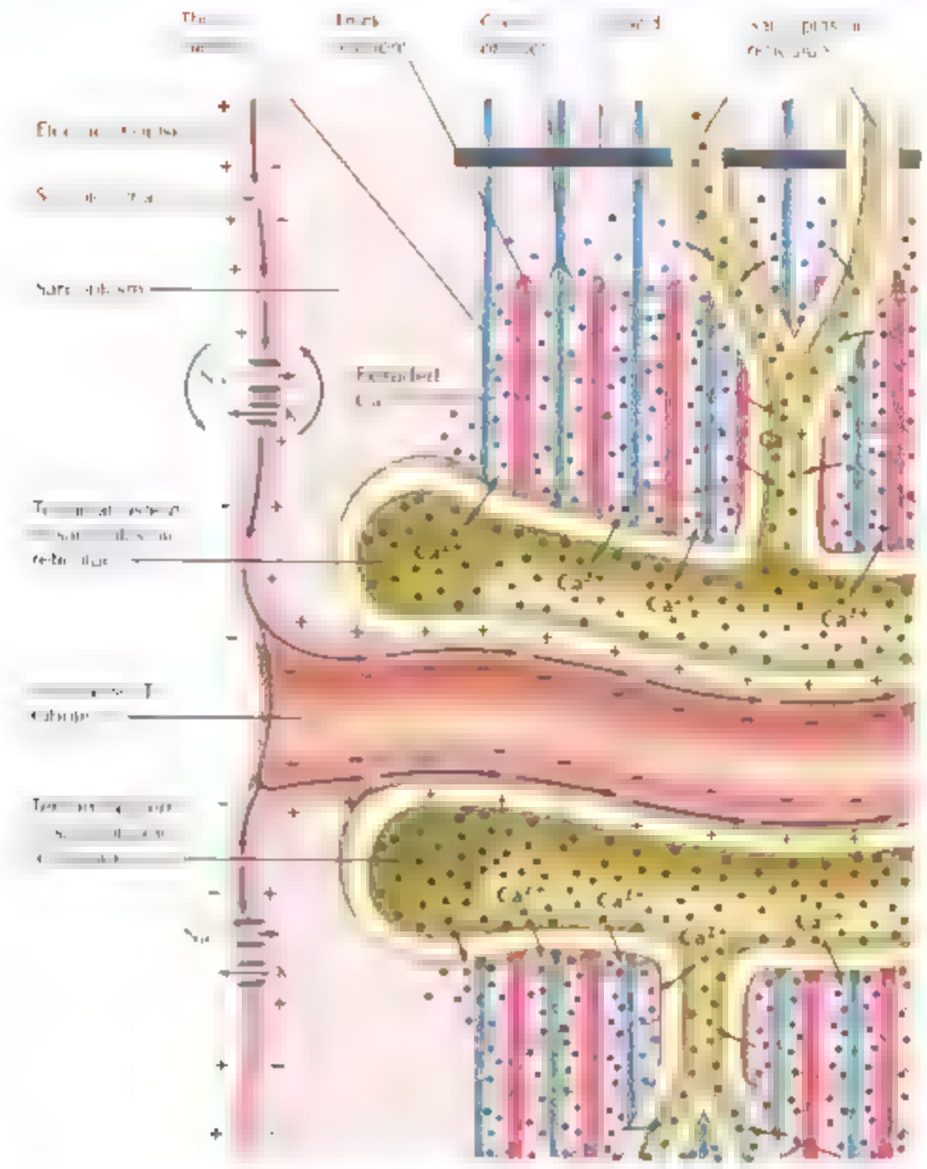


FIGURE 3.3 EXCITATION-CONTRACTION COUPLING

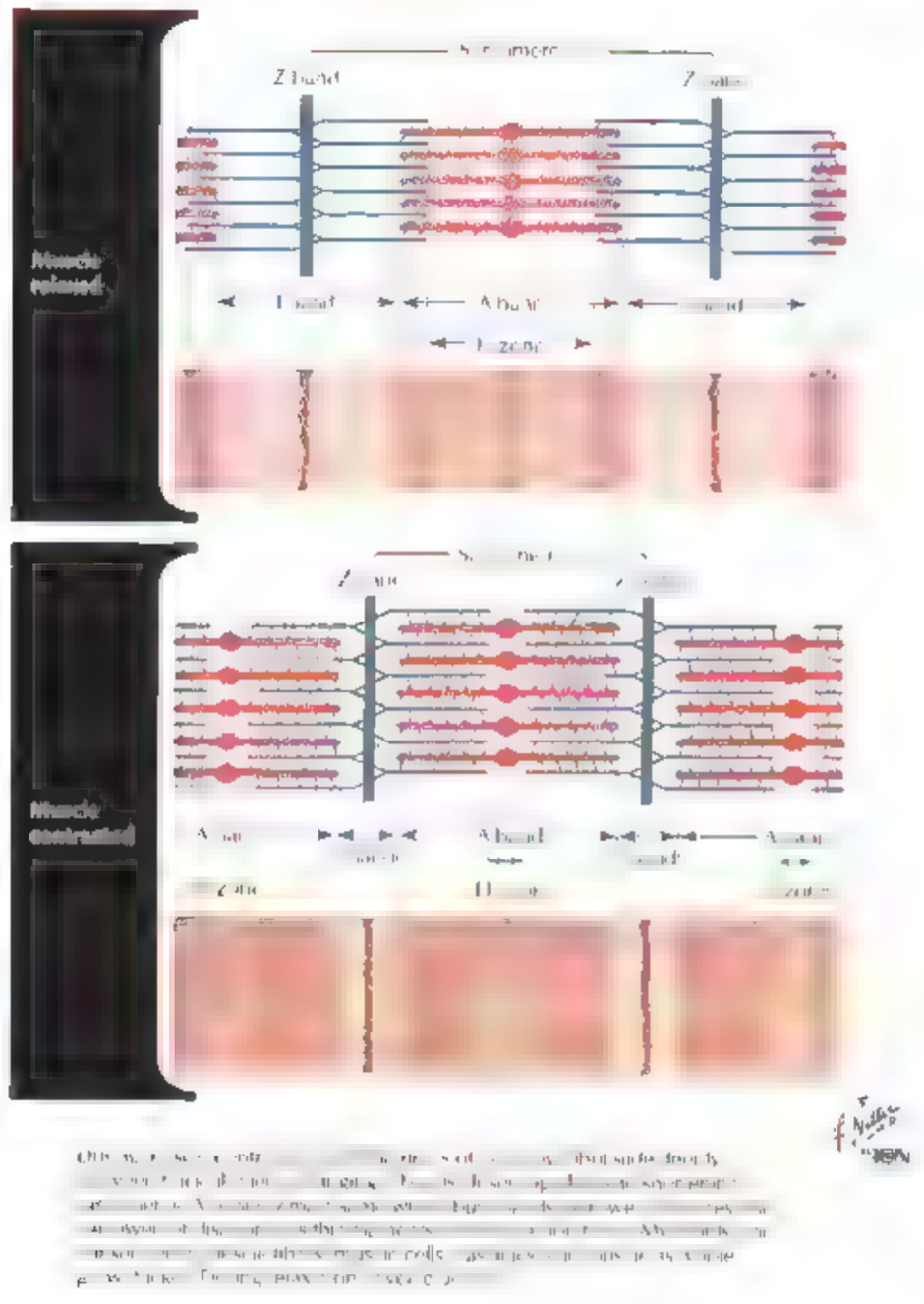


FIGURE 3.4 MUSCLE CONTRACTION AND RELAXATION

The sliding of the actin and myosin filaments [illegible] as the sliding actions [illegible] multiple cross-bridges [illegible]

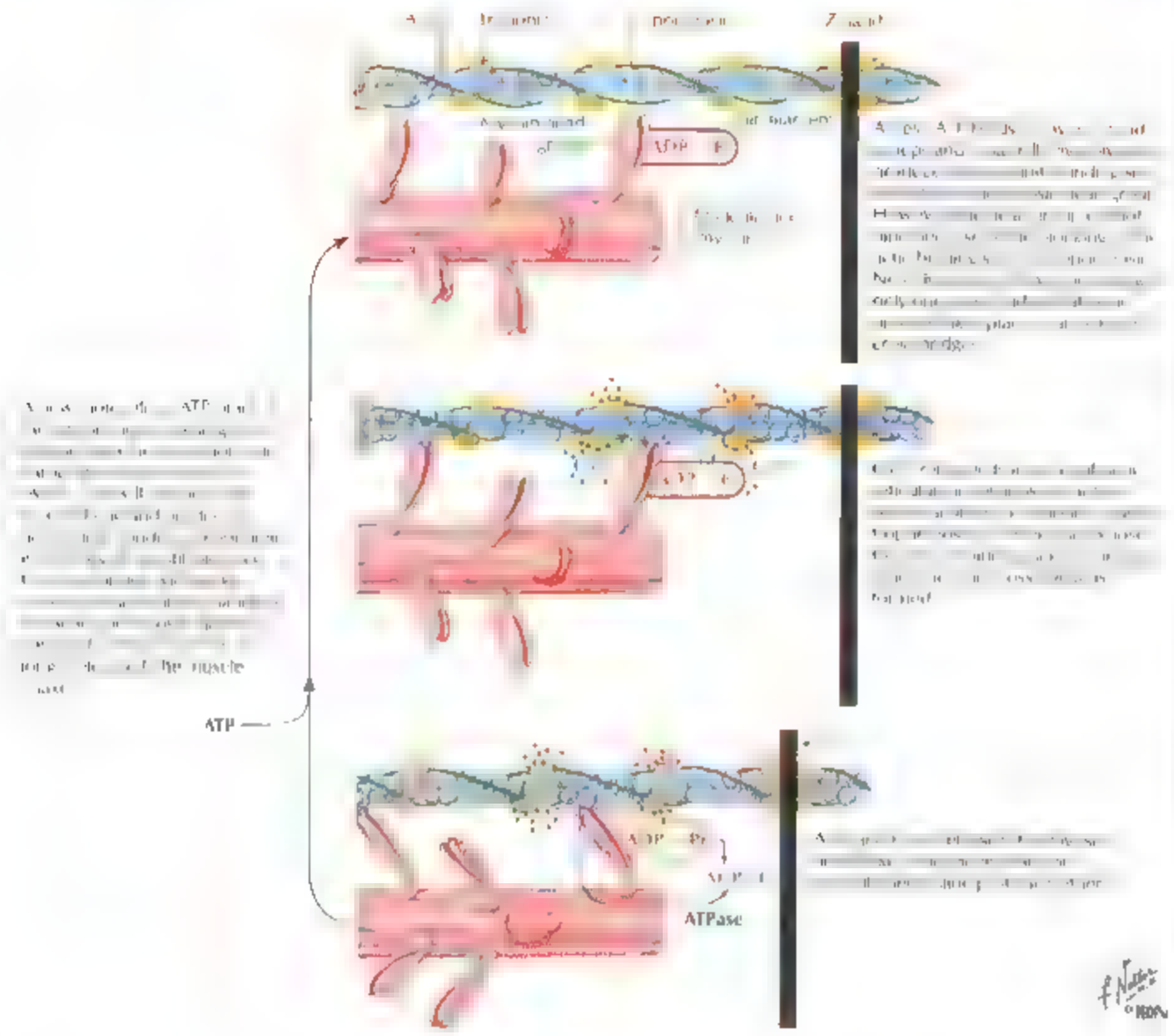


FIGURE 3.5 BIOCHEMICAL MECHANICS OF MUSCLE CONTRACTION

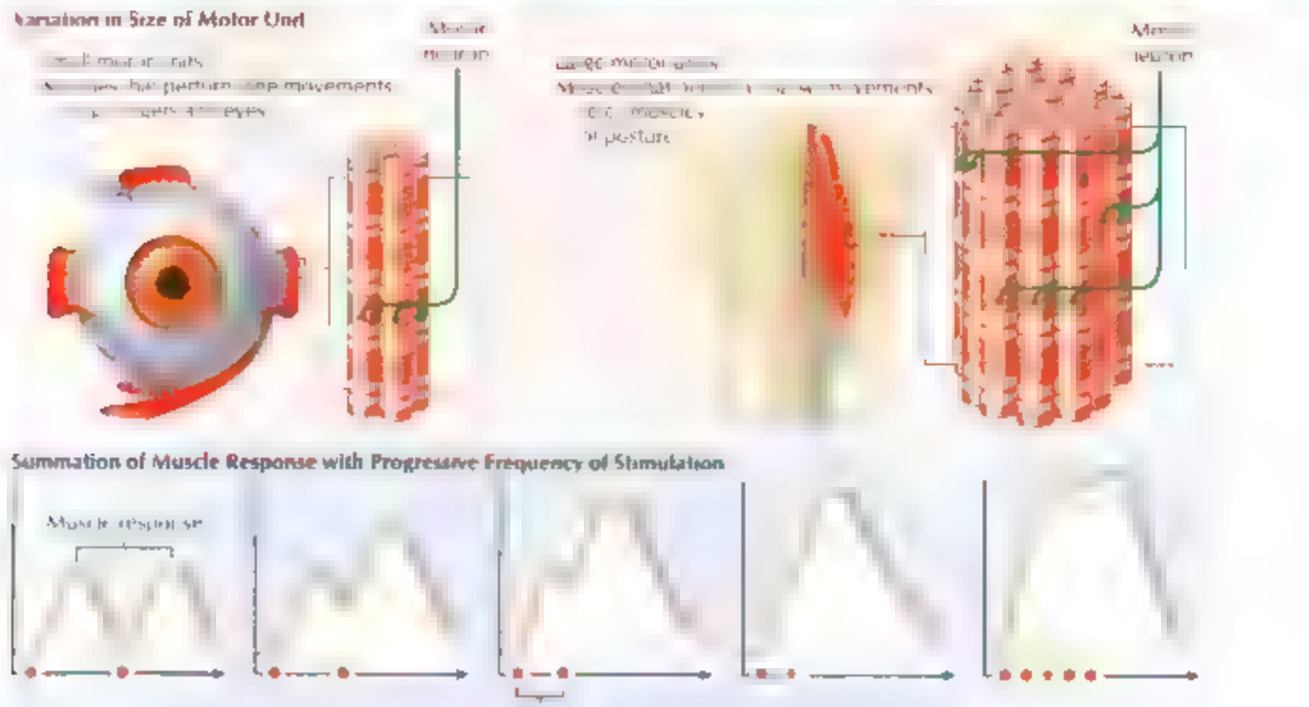


FIGURE 3.6 GRADING OF MUSCLE TENSION AND LENGTH-TENSION RELATIONSHIP

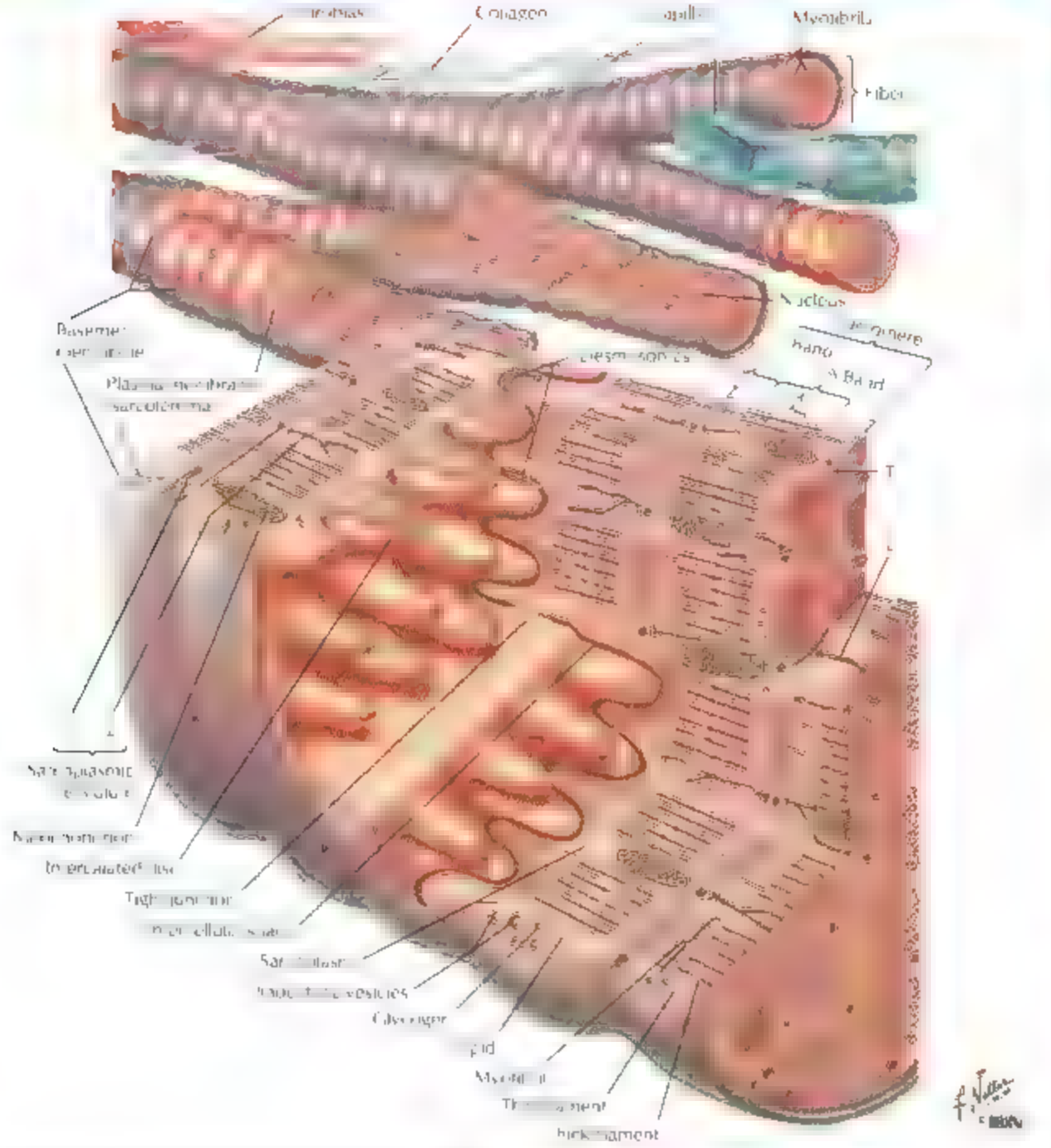


FIGURE 3 7 SCHEMA OF STRUCTURE OF CARDIAC MUSCLE

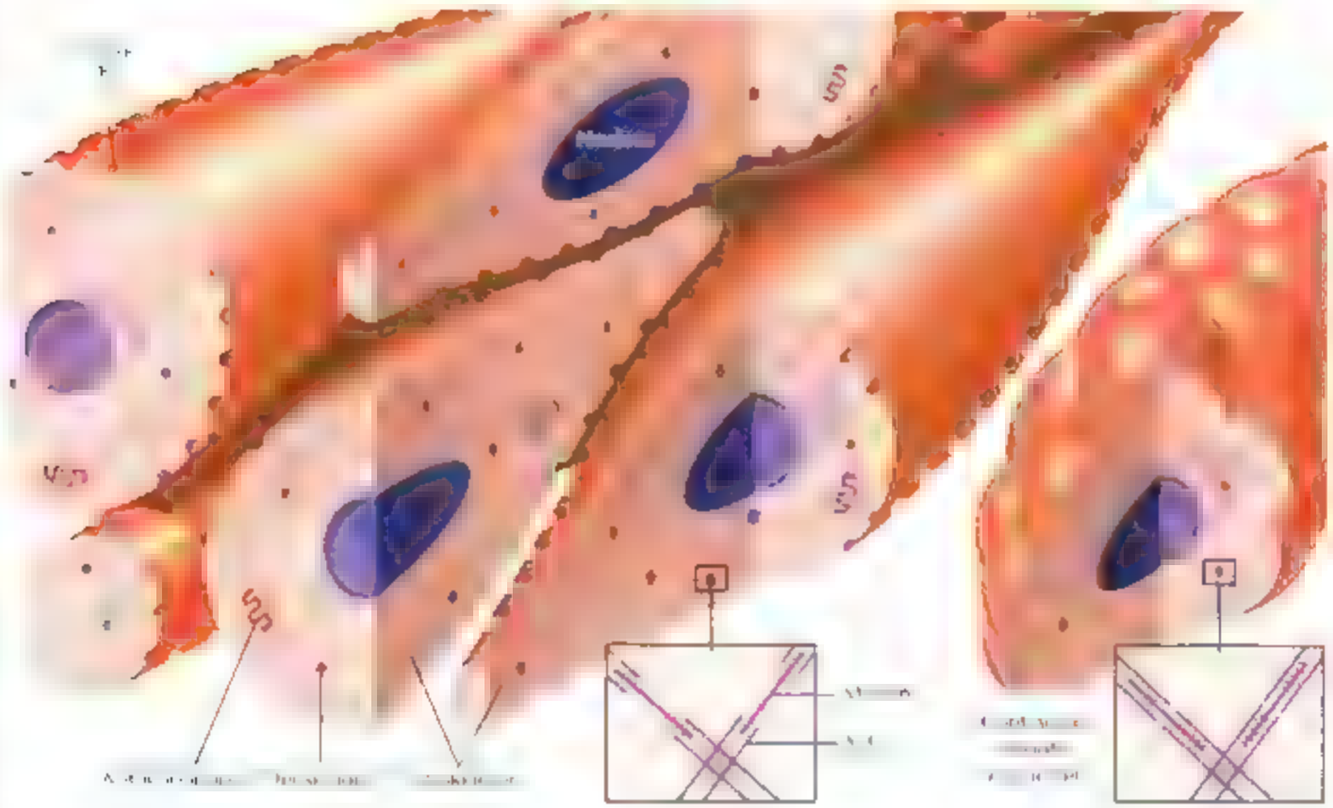


FIGURE 3 8 SMOOTH MUSCLE STRUCTURE

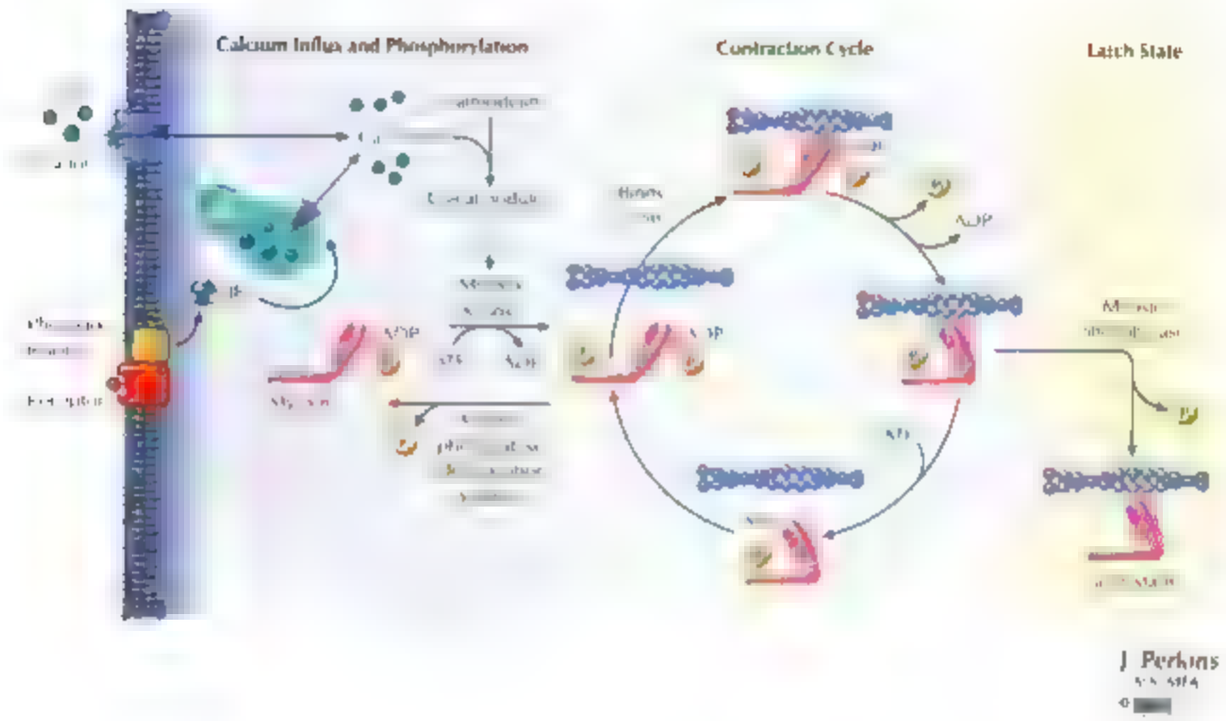


FIGURE 3.9 EXCITATION-CONTRACTION COUPLING OF SMOOTH MUSCLE

PART 3 | COMPARISION OF MUSCLE STRUCTURE AND FUNCTION

	Skeletal Muscle	Cardiac Muscle	Smooth Muscle
Structure			
Morphology	Long, cylindrical	Branched	Spindle-shaped
Nuclei	Multiple, located peripherally	One (sometimes two); located centrally	One; located centrally
Striations	Yes, striated pattern	Yes, striated pattern	No
Tubules	Yes, forms triad with sarcoplasmic reticulum	Yes, forms dyad with sarcoplasmic reticulum	No; caveolae
Electrical coupling cells	No	Yes, intercalated discs contain gap junctions	Yes, gap junctions
Regeneration	Yes, via satellite cells	No	Yes
Mitosis	No	No	Yes
Physiology			
Extracellular Ca^{2+} required for contraction	No	Yes	Yes
Regulation of cross-bridge formation	Ca^{2+} binding to troponin	Ca^{2+} binding to troponin	Ca^{2+} calmodulin activation of myosin kinase and phosphorylation of myosin
Control of contraction	Motor neurons	Autonomic nerves, β-adrenergic agonists	Autonomic nerves, hormones
Summation with increased stimulus frequency	Yes	No	Yes
Tension varies with filament overlap	Yes	Yes	Yes

Comparison of structure and function of skeletal, cardiac, and smooth muscle tissue.

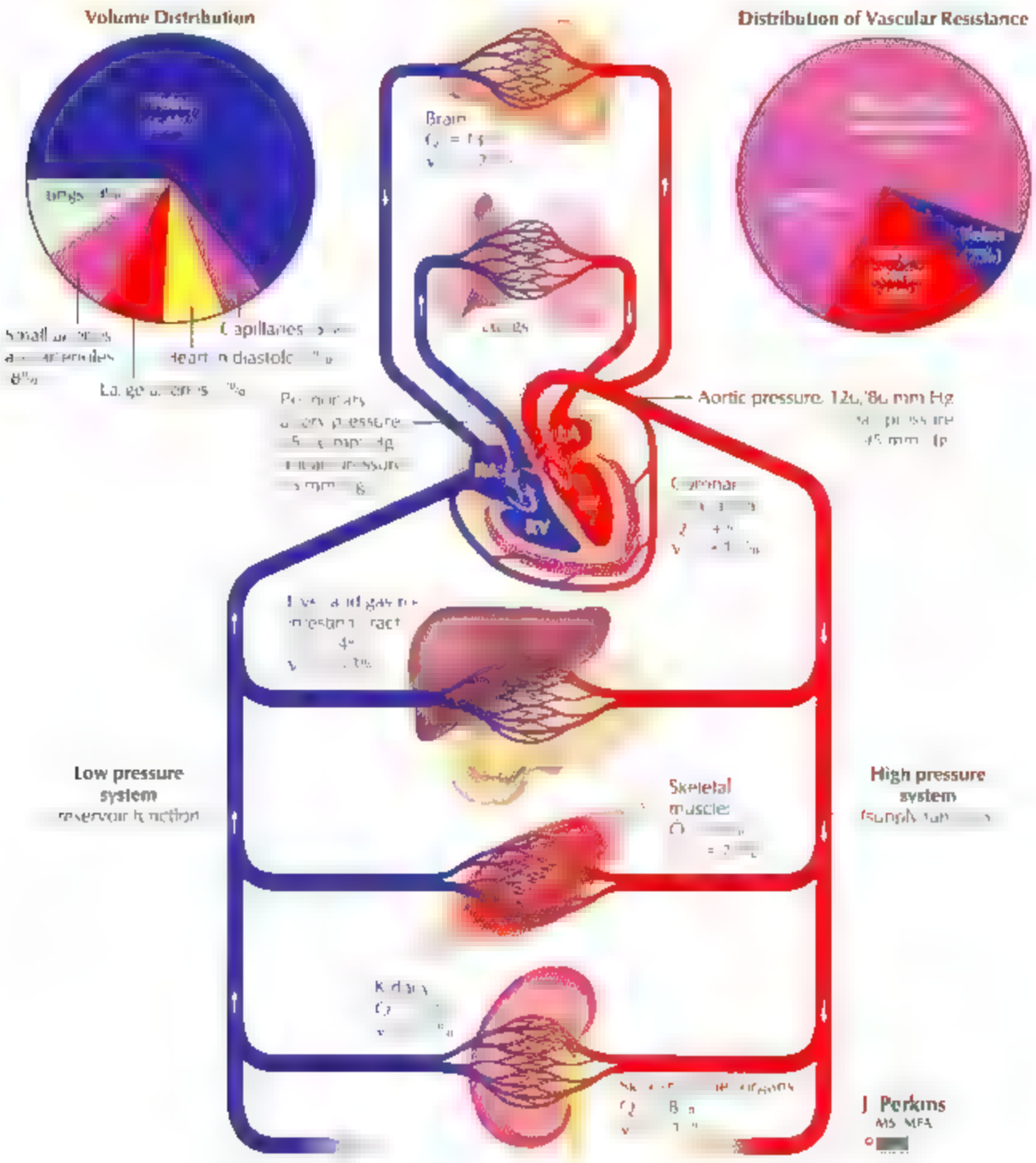


FIGURE 4.1 CARDIOVASCULAR SYSTEM OVERVIEW

The cardiovascular system consists of the heart, which pumps blood through the pulmonary circulation for the exchange of O_2 and CO_2, and the systemic circulation to supply all other tissues of the body. At rest, cardiac output is approximately 5 L/min in both the pulmonary and systemic circulations. The amount of blood flow ($\dot{Q}$) as a percentage of cardiac output, and relative percentage of oxygen extraction, are shown for various organ systems. Approximately 64% of the blood volume resides in the veins, and is returned to the right side of the heart. Vascular resistance is primarily a function of the small muscular arteries and arterioles.

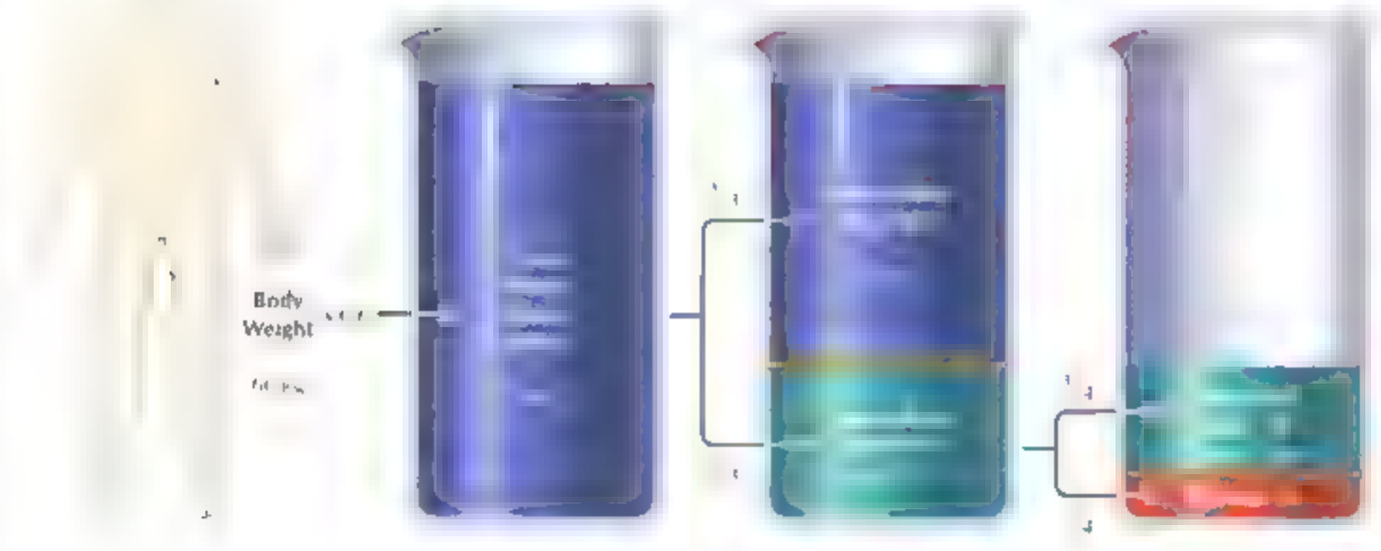


FIGURE 4.2 BODY FLUID COMPARTMENTS

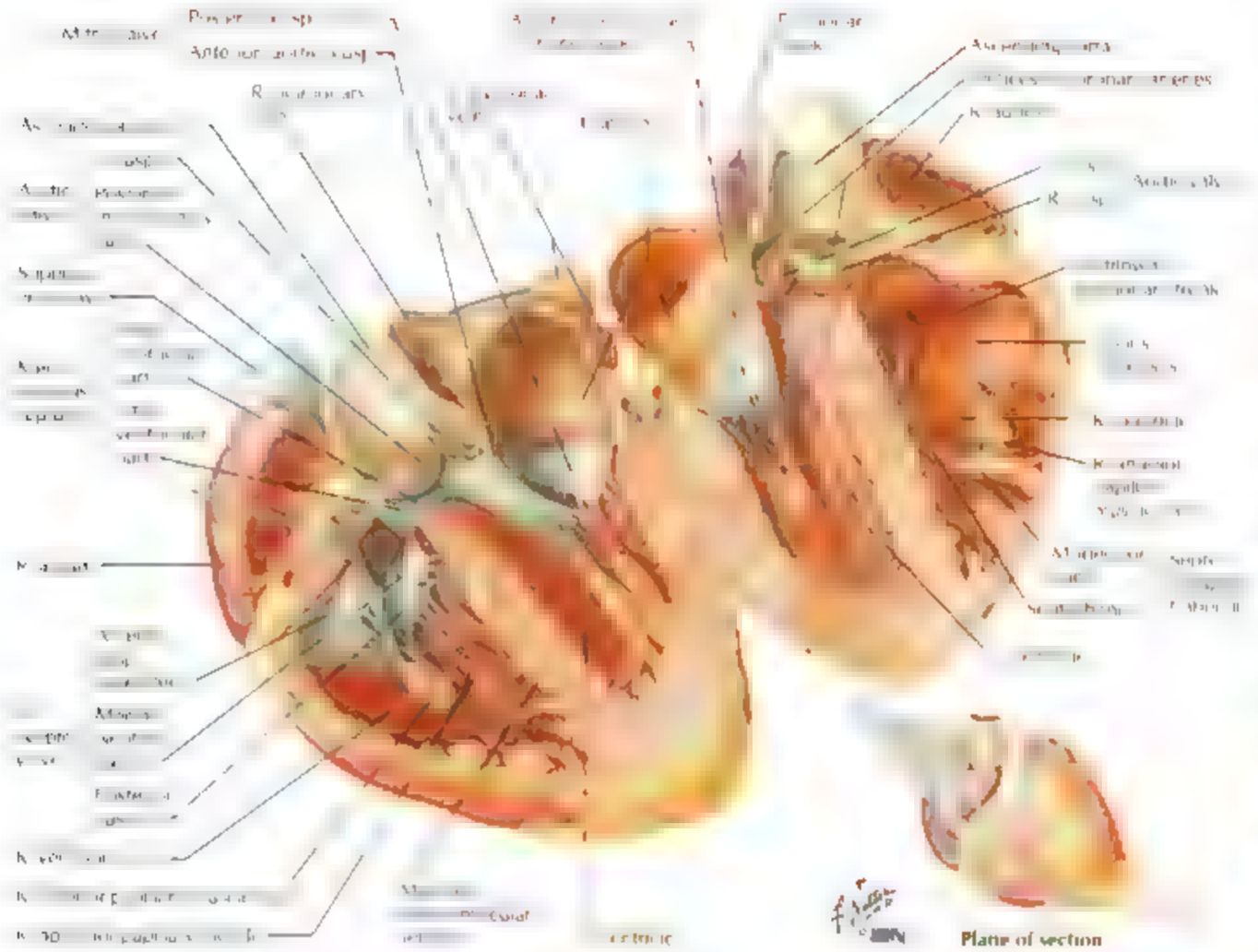


FIGURE 4.3 STRUCTURE OF HEART

This section shows the heart during ventricular systole. Blood is being pumped from the right ventricle into the pulmonary trunk and from the left ventricle into the aorta. The work of the left ventricle is greater than that of the right ventricle because the systemic circulation has a higher resistance than the pulmonary circulation. The walls of the left ventricle are correspondingly thicker.

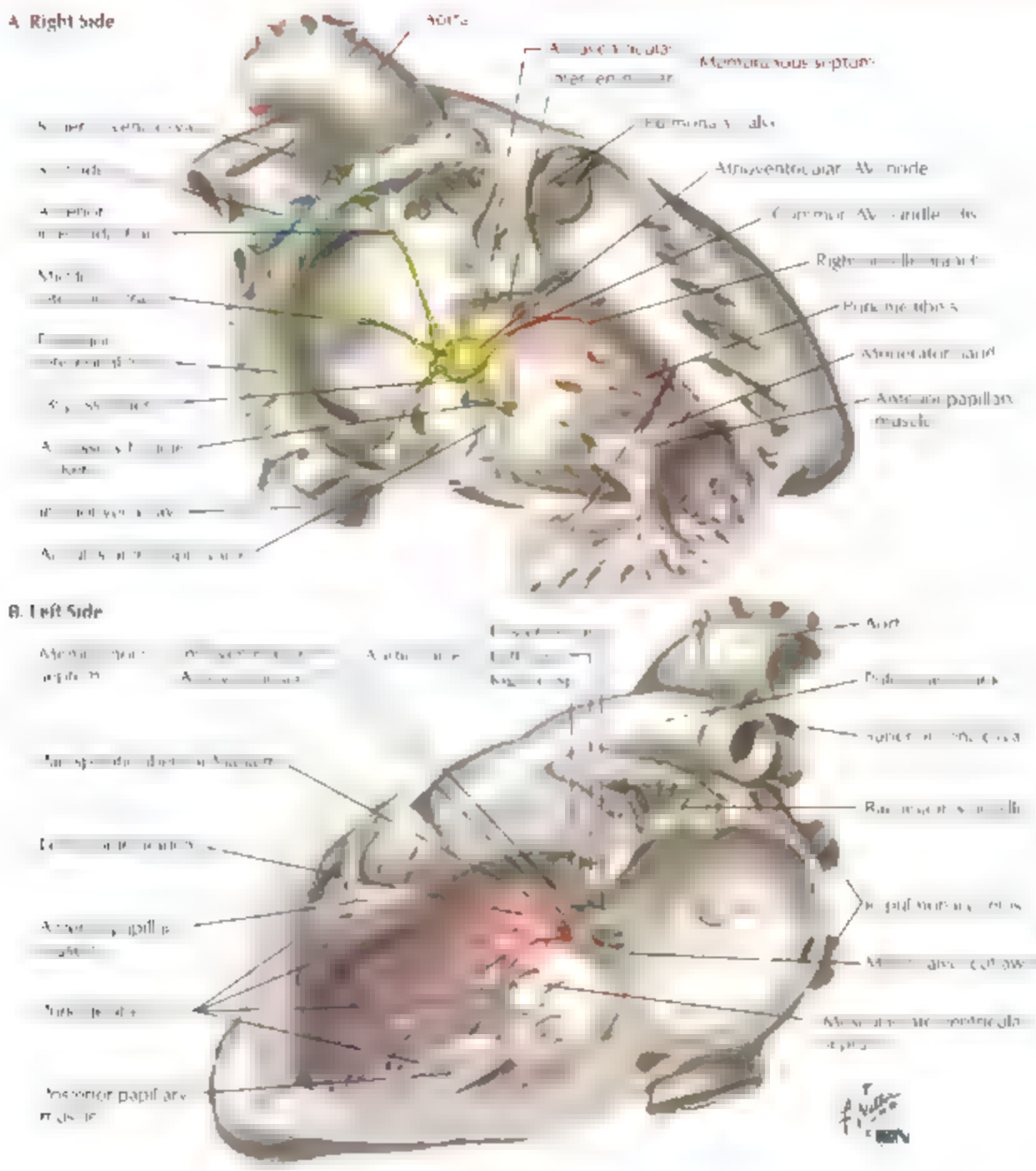


FIGURE 4.4 ANATOMY OF THE SPECIALIZED CONDUCTION SYSTEM

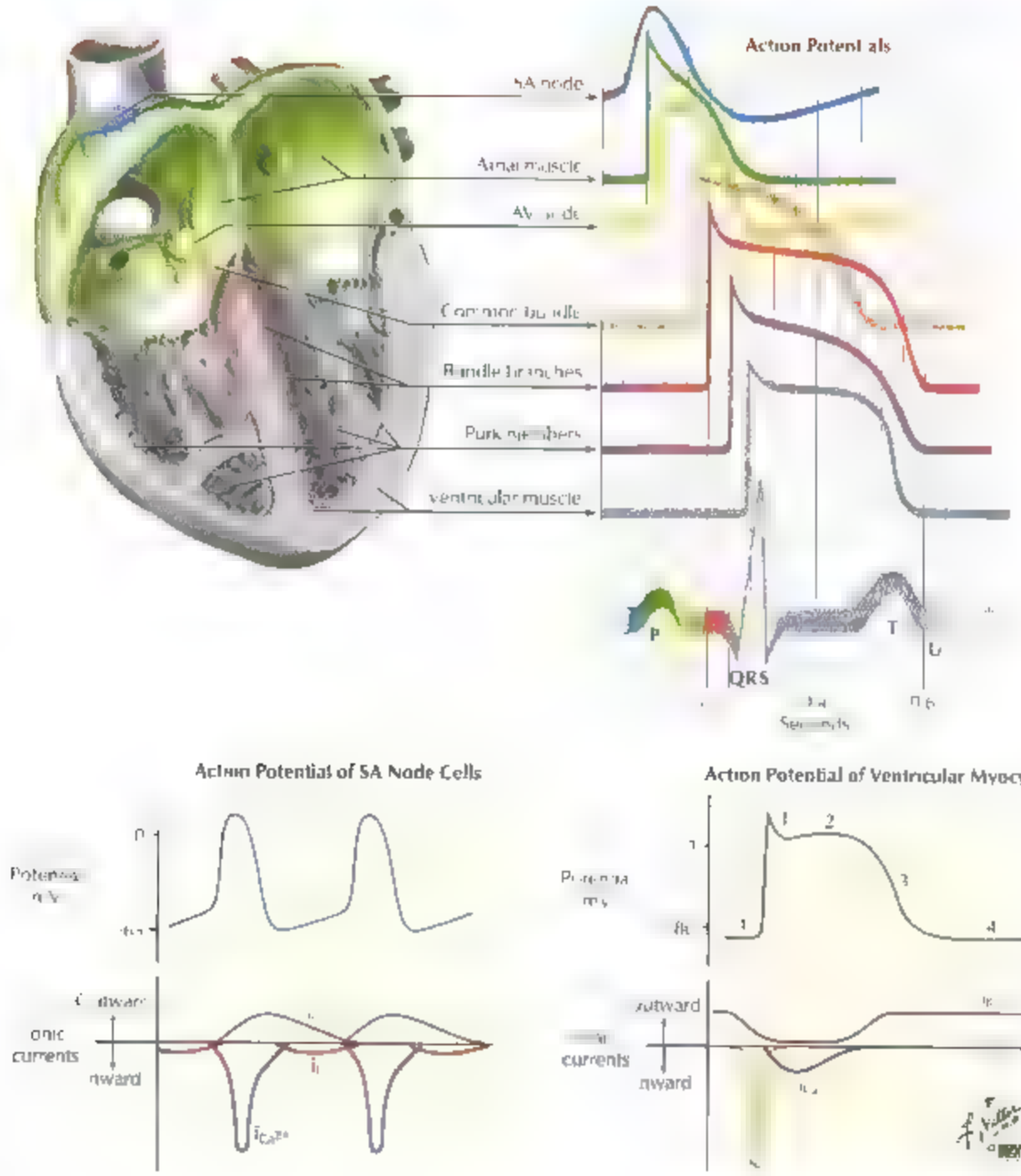


FIGURE 4.5 ELECTRICAL ACTIVITY OF THE HEART

The normal pumping of blood through the chambers of the heart requires the precisely timed spread of action potentials through the heart's conduction system and the atrial and ventricular muscle. The rate of the heartbeat is set by spontaneously generated action potentials in the cells of the SA node. The frequency of SA node action potentials is regulated by the autonomic nervous system. Sympathetic stimulation of the SA node increases principally I_{Na} current and I_f, which depolarizes the cell and thereby increases the rate. Parasympathetic stimulation increases I_K, which hyperpolarizes the cell and thereby decreases the heart rate. The ventricular muscle action potential has a prolonged depolarization phase resulting from I_{Ca} flux. This ionic plateau phase prevents summation and tetanus at even high heart rates.

Normal Sequence of Cardiac Depolarization and Repolarization and Derivation of ECG

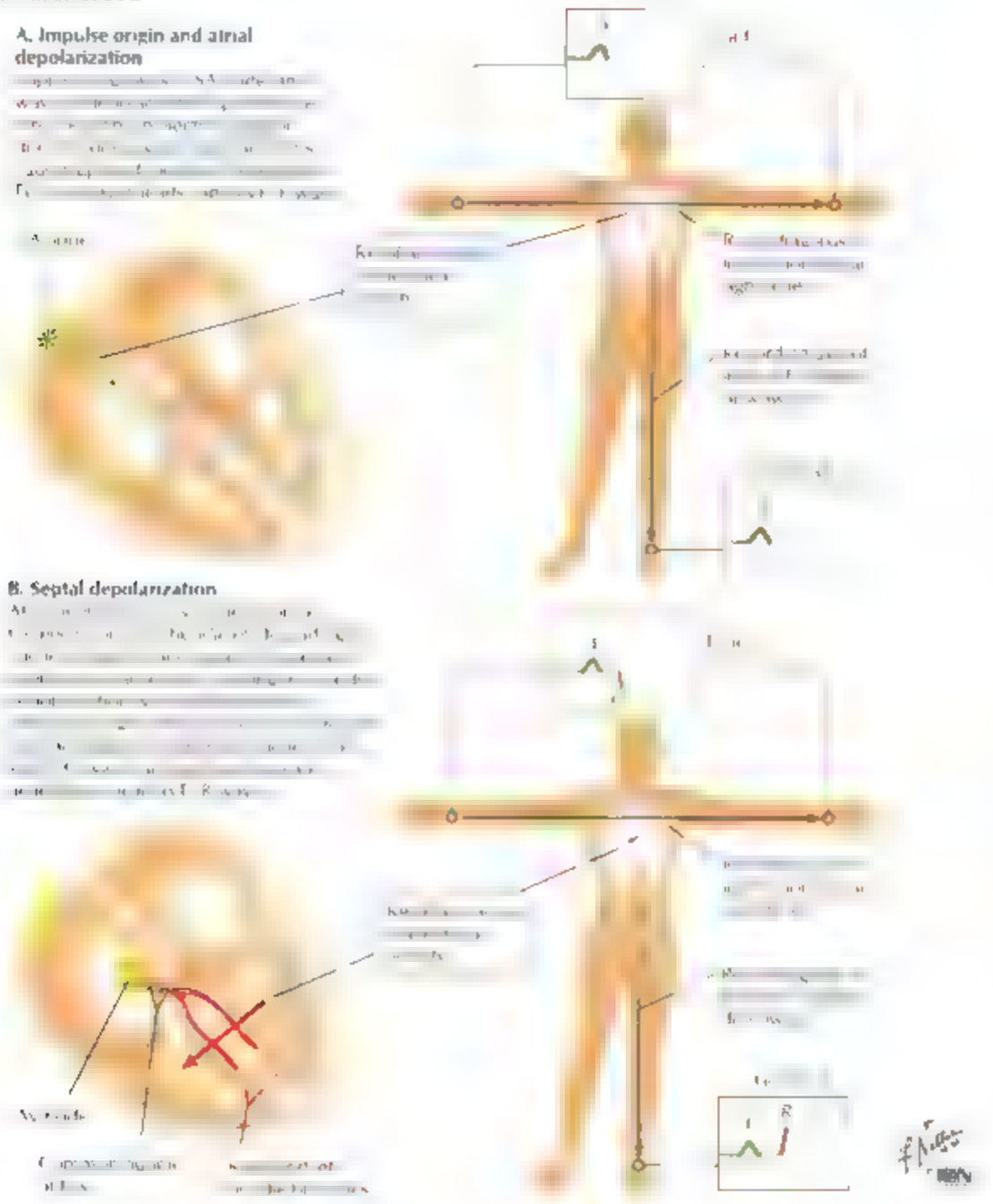
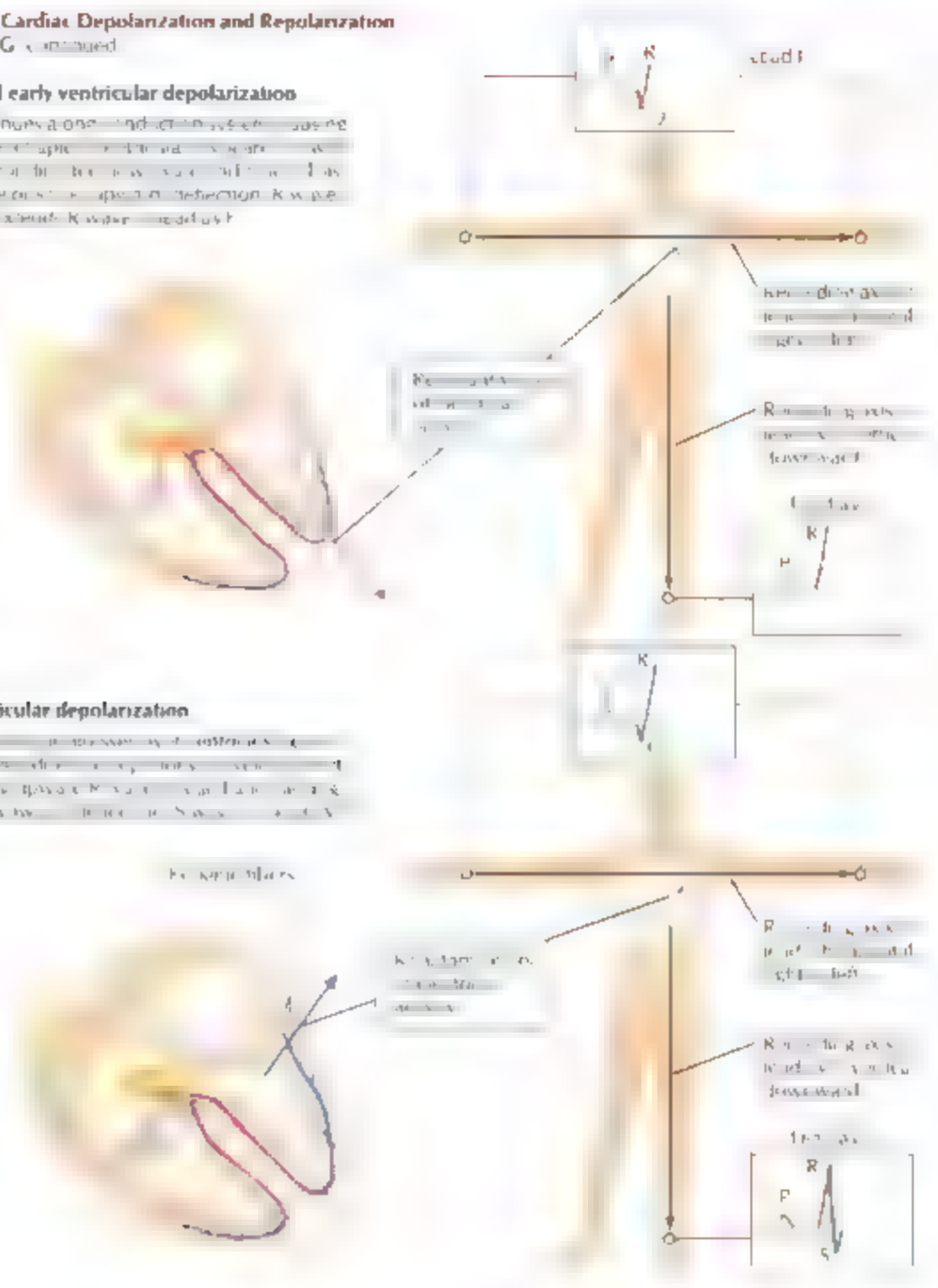


FIGURE 4.6 CARDIAC DEPOLARIZATION AND REPOLARIZATION PART 1

Normal Sequence of Cardiac Depolarization and Repolarization and Derivation of ECG (continued)

C. Apical and early ventricular depolarization

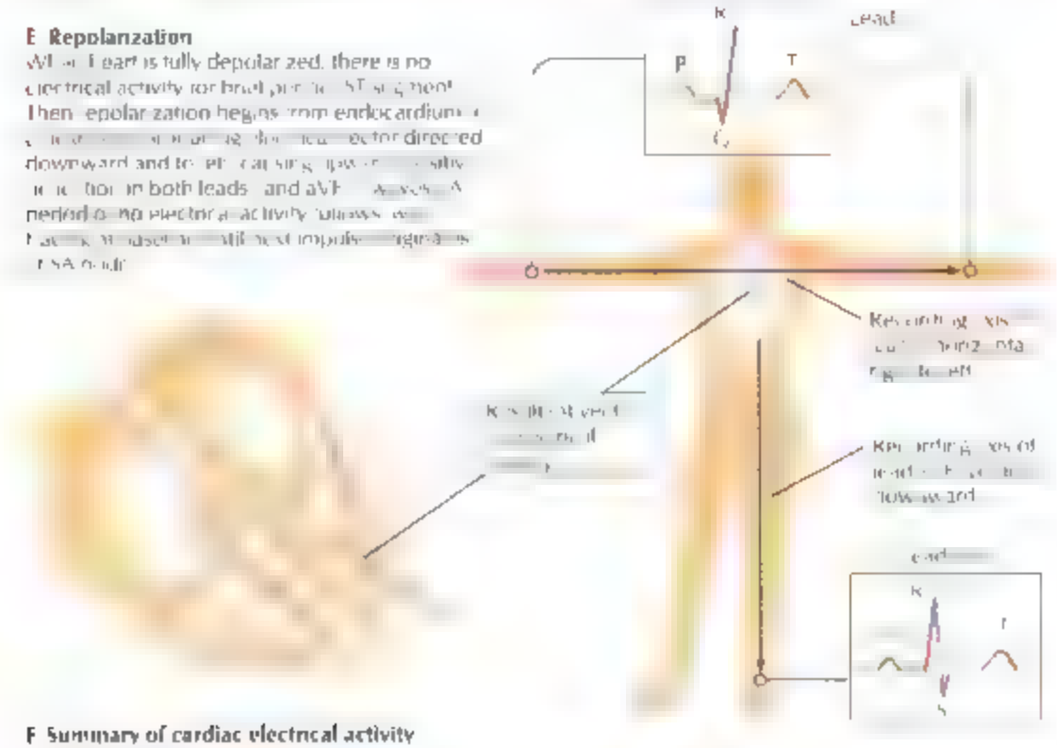


D. Late ventricular depolarization

FIGURE 4.7 CARDIAC DEPOLARIZATION AND REPOLARIZATION PART 2

Normal Sequence of Cardiac Depolarization and Repolarization and Derivation of ECG (continued)

E Repolarization



F Summary of cardiac electrical activity

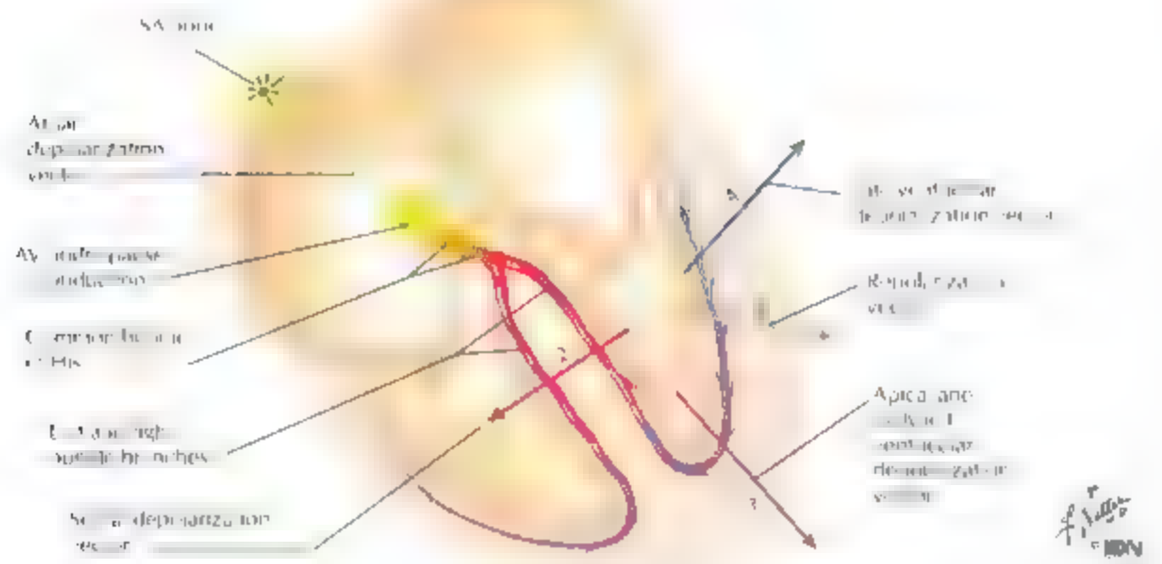


FIGURE 4.8 CARDIAC DEPOLARIZATION AND REPOLARIZATION PART 3

F, Continued. Once fully depolarized, electrical activity ceases briefly, and the ST segment of the ventricular contraction wave begins. Repolarization begins in the outer epicardium and ends in the inner endocardium. The T wave of the ECG is generated by repolarization of the ventricles. Repolarization may also produce a small U wave.

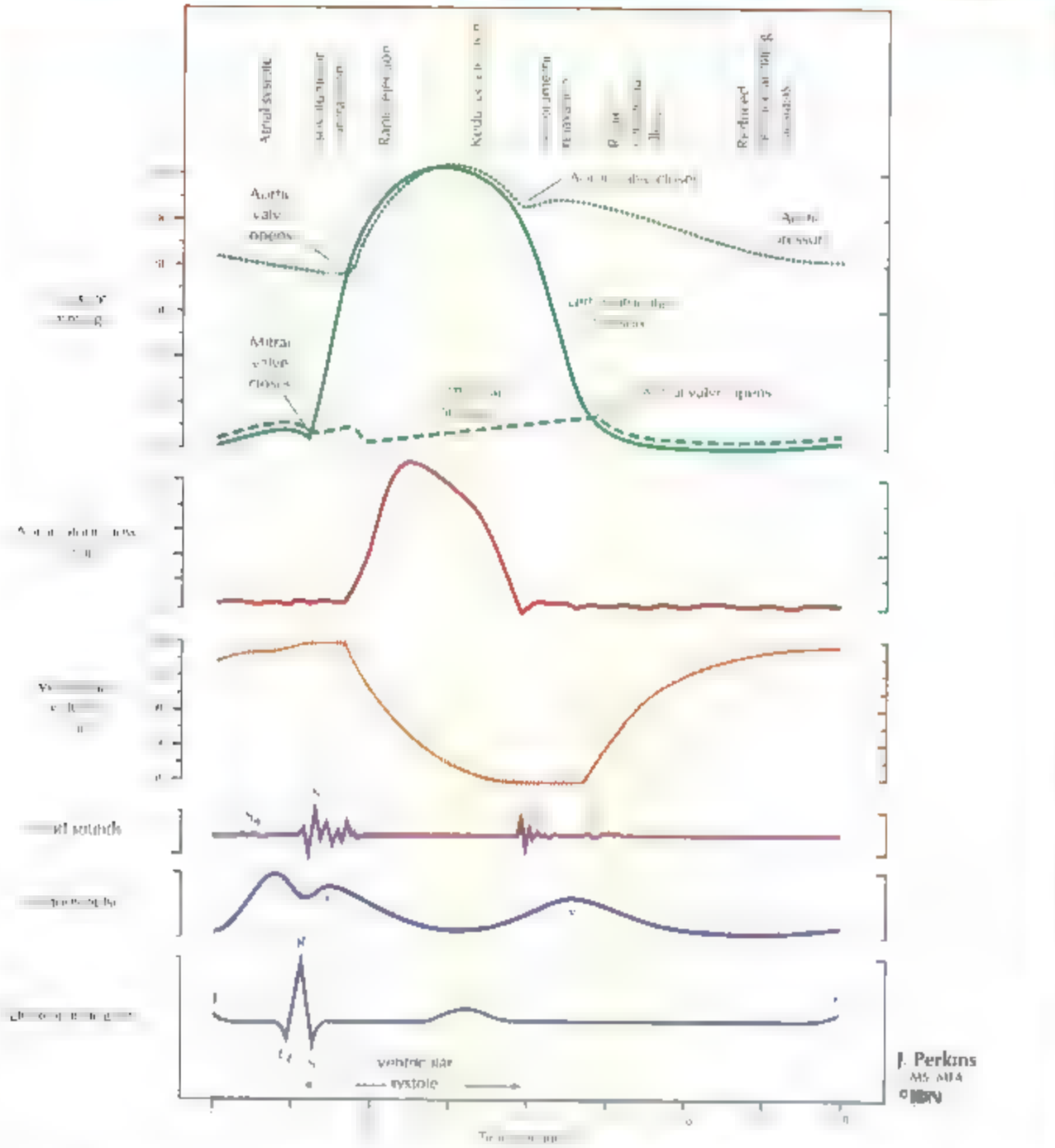


FIGURE 4.9 CARDIAC CYCLE

The cardiac cycle represents one complete sequence of atrial and ventricular contraction and relaxation. Arrows indicate the key electrical and hemodynamic events associated with a single cycle. Changes in left atrial, ventricular, and aortic pressure, left ventricular volume, heart sounds, jugular venous pressure, and the ECG are shown. The S1 heart sound results from closure of the mitral and tricuspid valves, while the S2 heart sound results from closure of the aortic and pulmonic valves. Rapid S3 and S4 heart sounds associated with filling of the ventricles. They are normally difficult to hear in healthy adults. S3 is heard in healthy children and young adults. S4 is associated with atrial hypertrophy and decreased ventricular compliance. The components of the jugular venous pulse wave (a, c, and v waves) result from bulging of the tricuspid valve into right atrium during right ventricular contraction, the backward movement of blood into the collapsed right atrium during the initial phase of ventricular diastole, and the forward movement of blood into the right atrium during the latter phase of ventricular diastole, respectively. The components of the ECG are described in Figures 4.6 and 4.7.

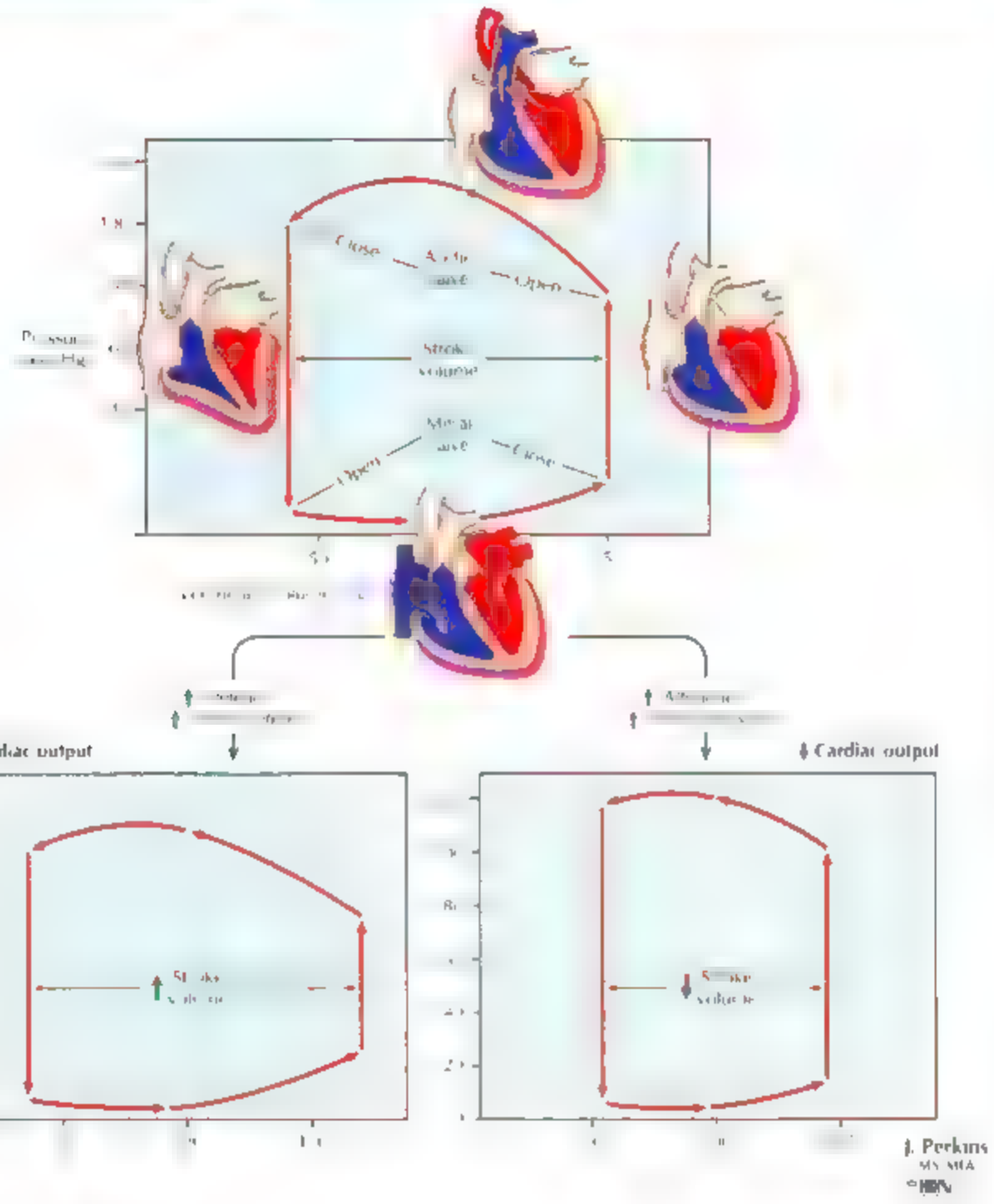


FIGURE 4.10 PRESSURE-VOLUME LOOP

volume

Stroke volume = End-diastolic volume − end-systolic volume

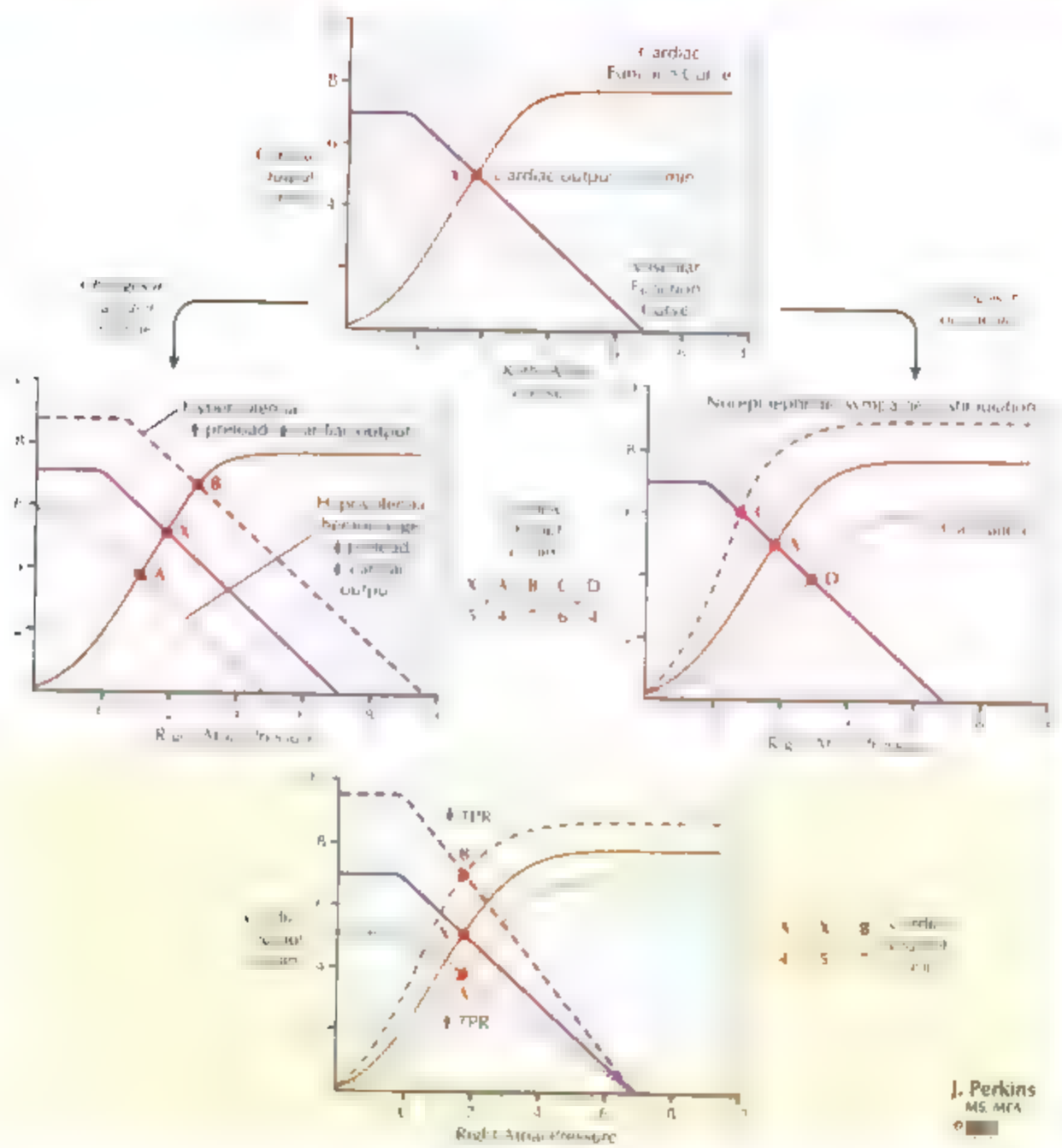


FIGURE 4.11 CARDIAC AND VASCULAR FUNCTION CURVES

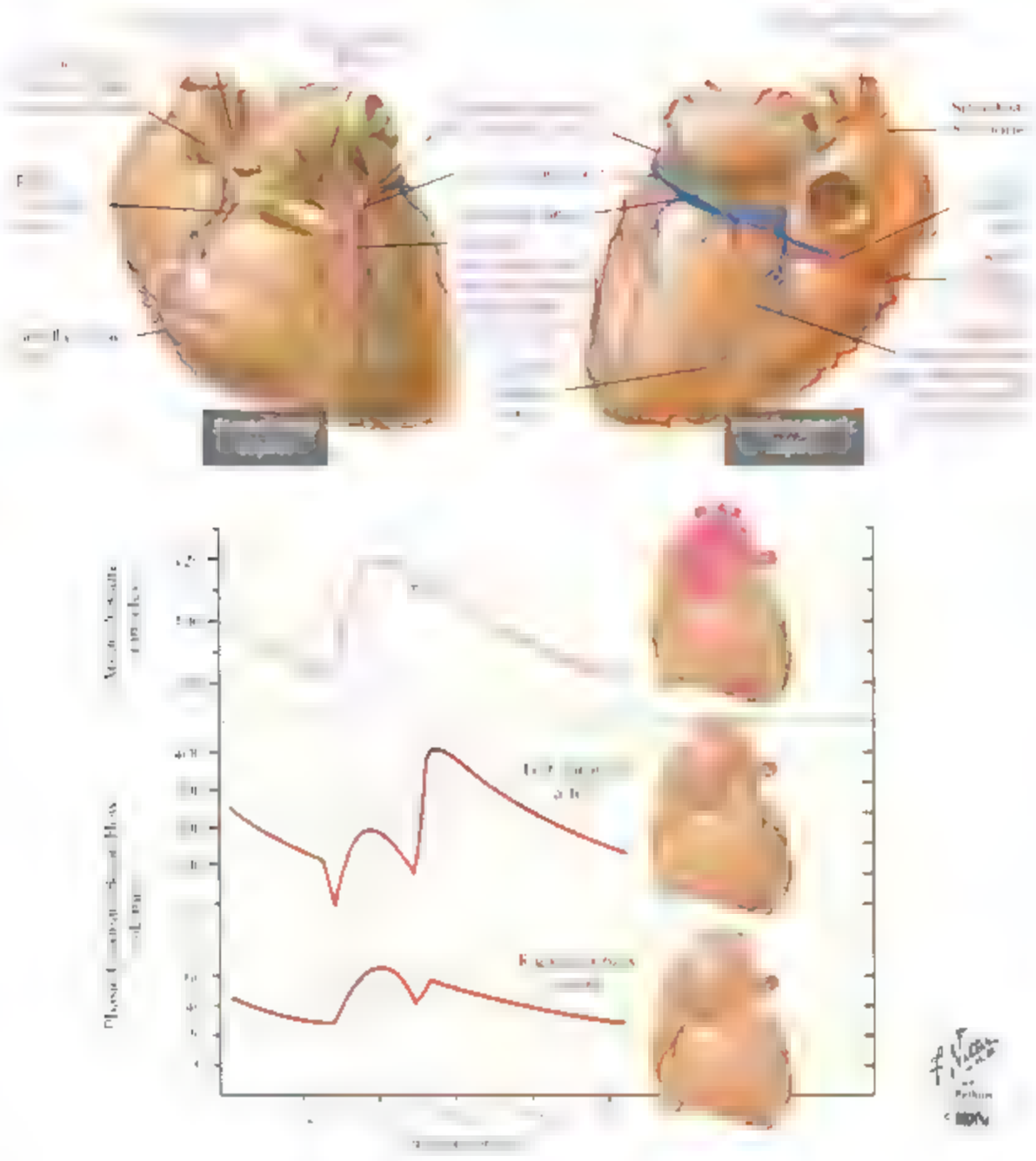


FIGURE 4.12 CORONARY CIRCULATION

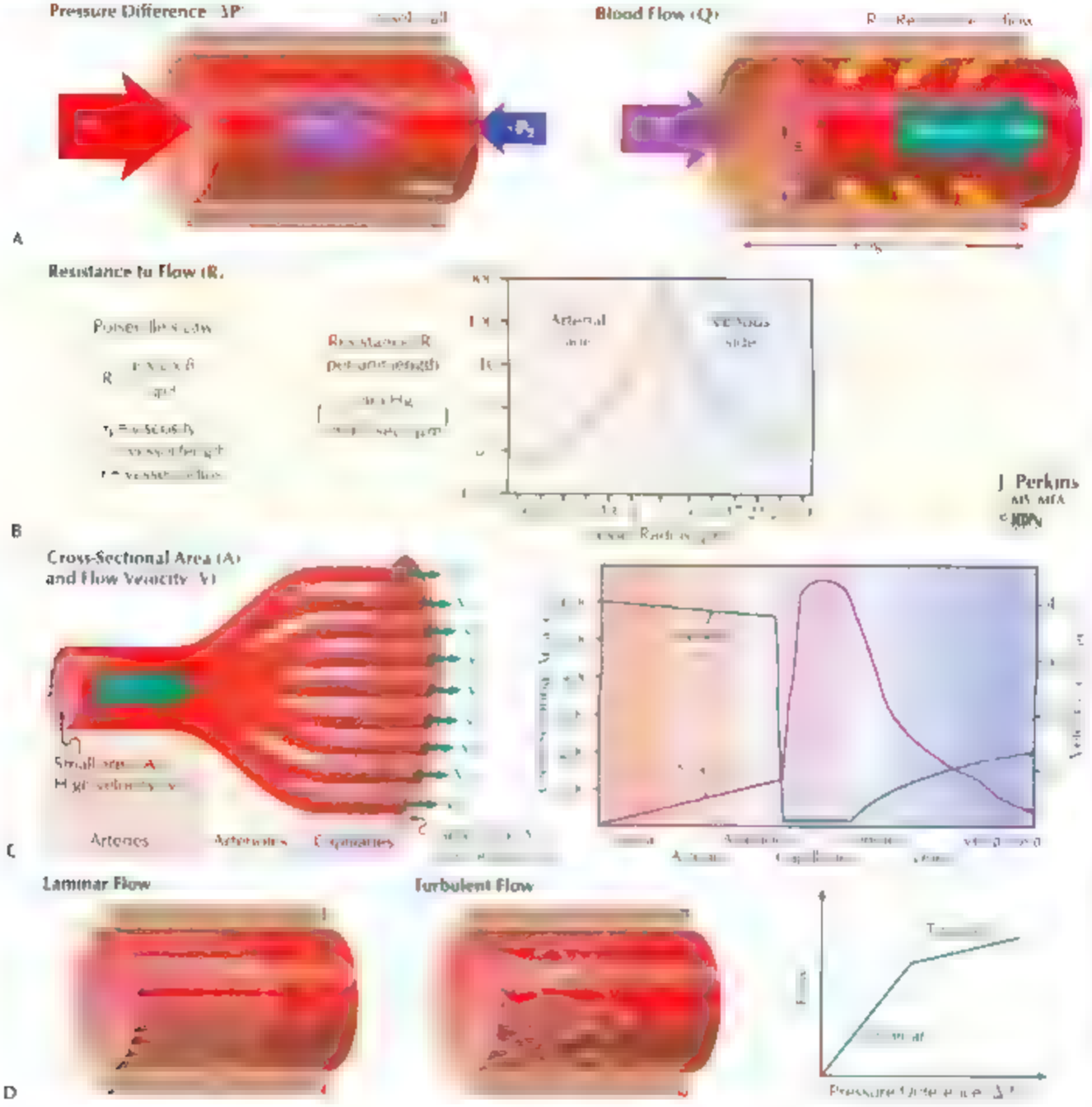


FIGURE 4.13 HEMODYNAMICS

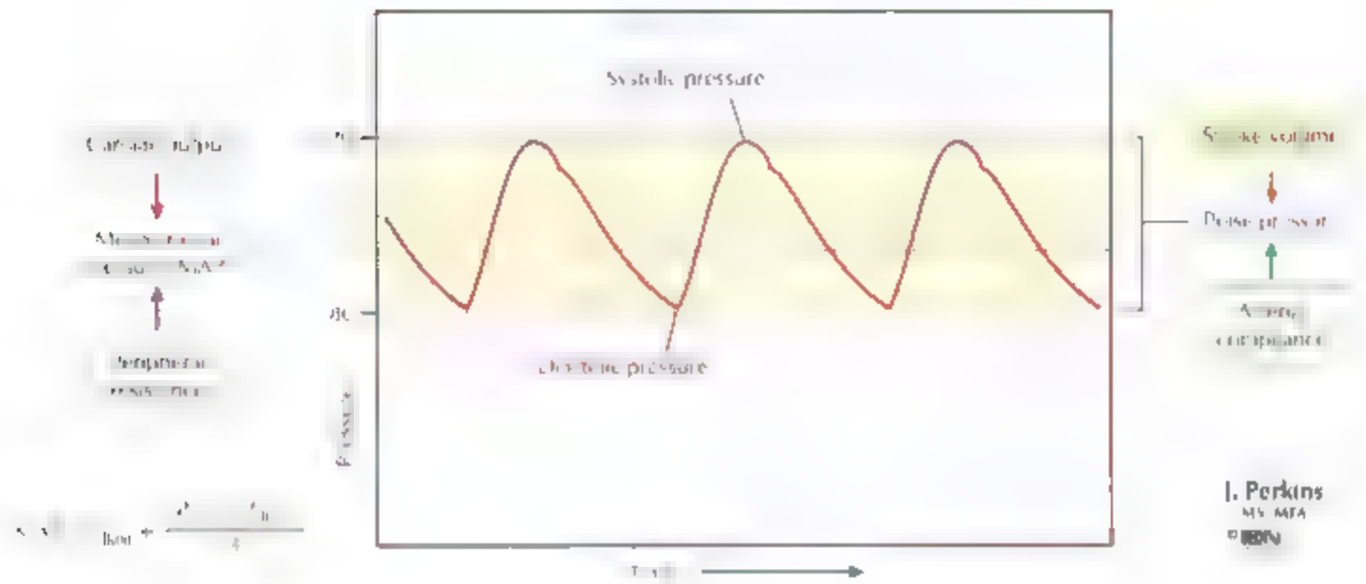


FIGURE 4.14 ARTERIAL PRESSURE

The [illegible] pressure (MAP) is the average pressure in the arteries during one cardiac cycle. It is determined by the cardiac output (CO) and the total peripheral resistance (TPR) as MAP = CO × TPR. As described in Figure 4.13, CO is determined by the stroke volume (SV) and heart rate (HR) as CO = SV × HR. Blood volume and vessel diameter (by the sympathetic nervous system and circulating hormones such as epinephrine) determine total peripheral resistance. The [illegible] pressure is pulsatile. The systolic pressure rises with SV and falls as blood flows into the arteries. The diastolic pressure is determined by the recoil of the arterial wall and the compliance of the arterial wall. Decreased compliance (as in arteriosclerosis) increases the systolic pressure and decreases the diastolic pressure. The pulse pressure is the difference between the systolic and diastolic pressures. Thus, decreased compliance increases the pulse pressure.

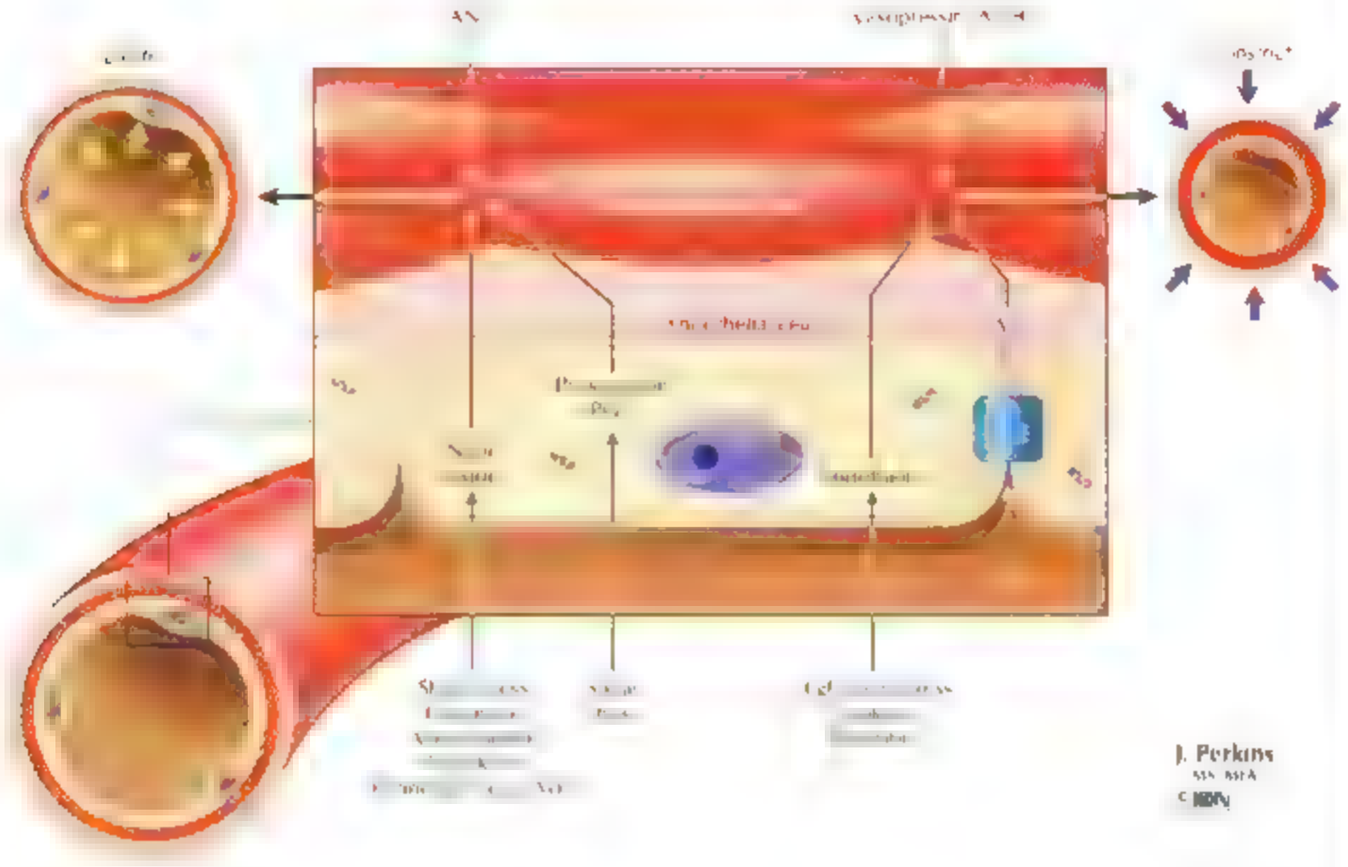


FIGURE 4.15 CONTROL OF ARTERIOLAR TONE

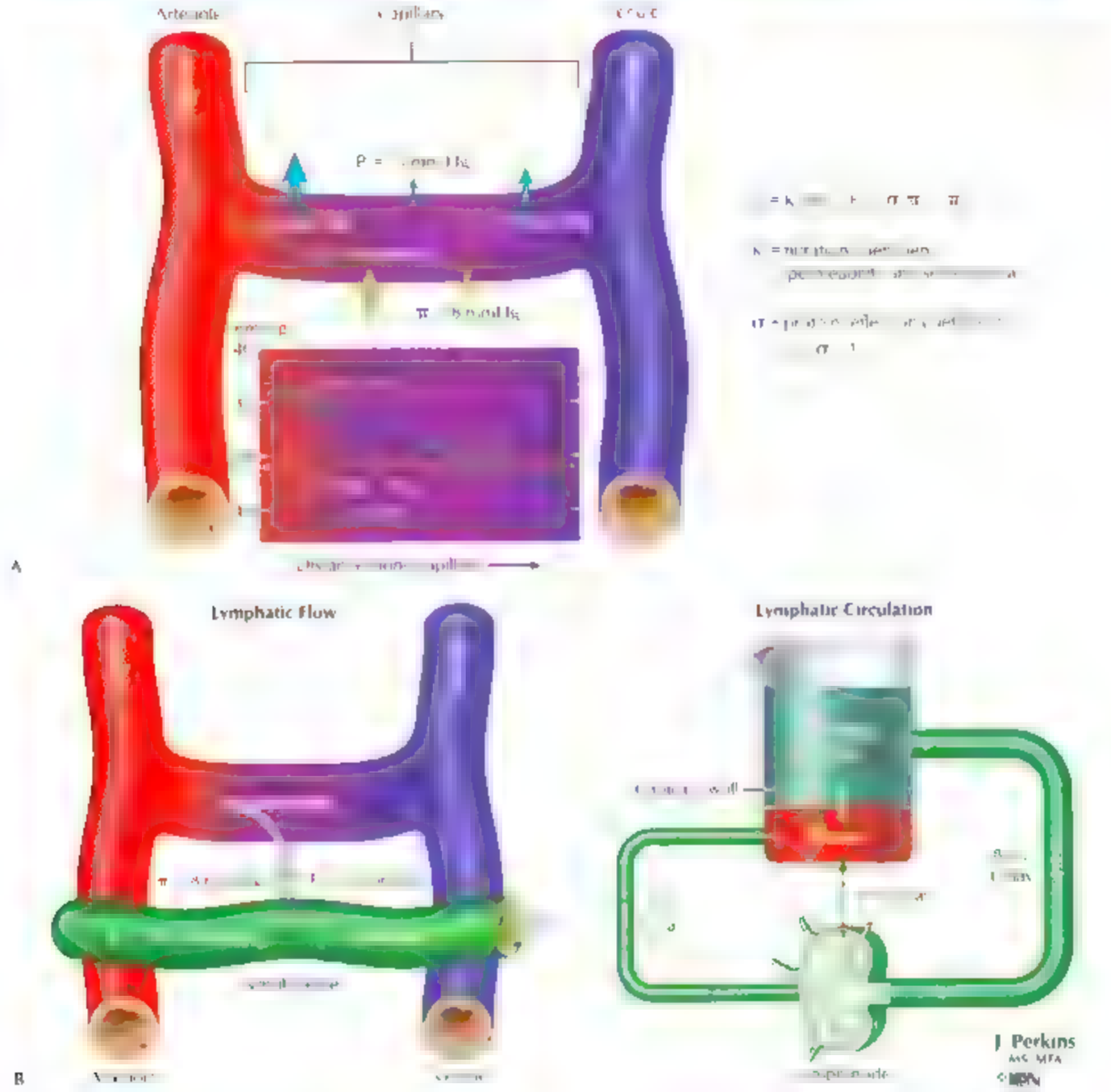


FIGURE 4.16 MICROCIRCULATION

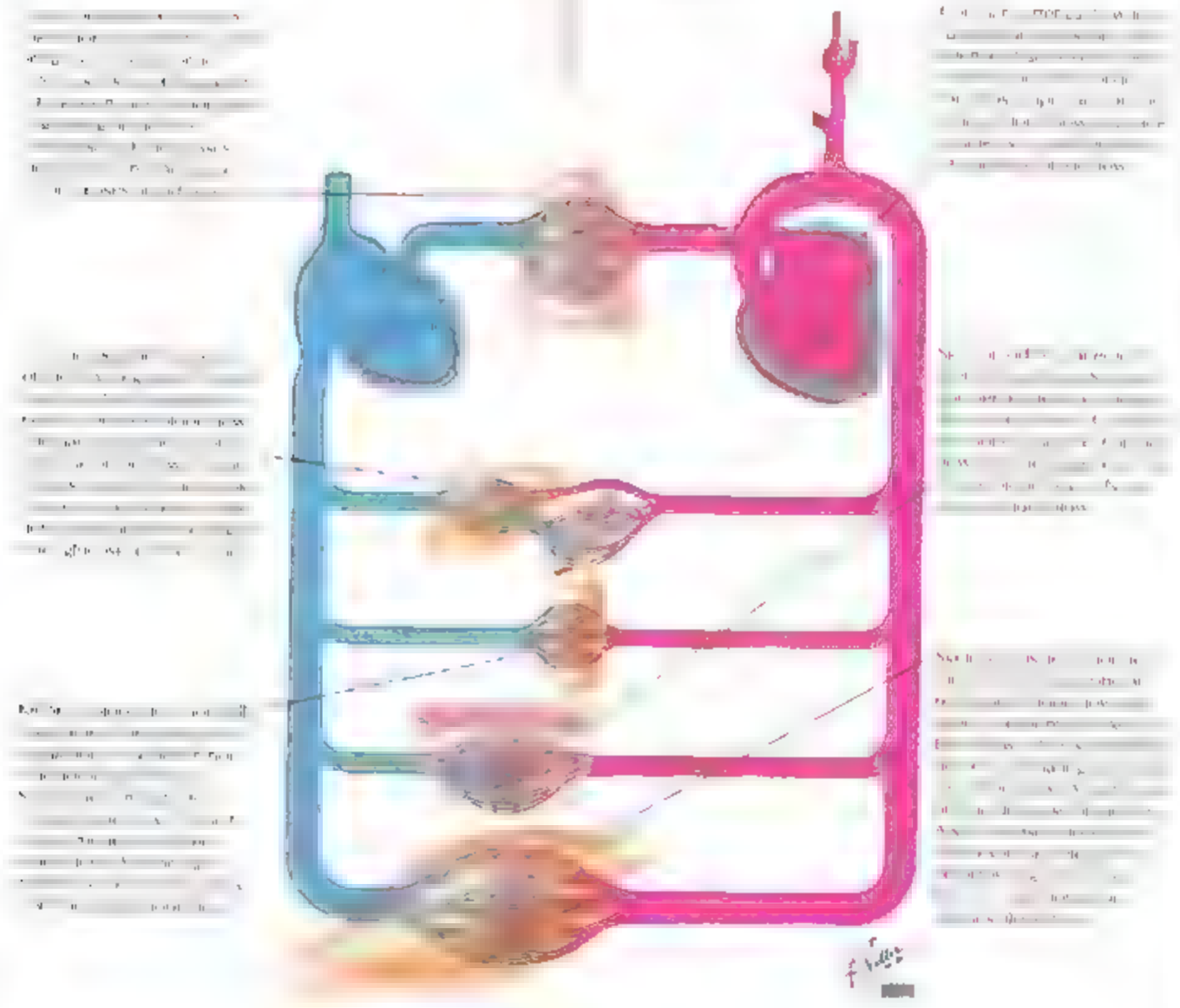


FIGURE 4.17 CIRCULATION TO SPECIAL REGIONS

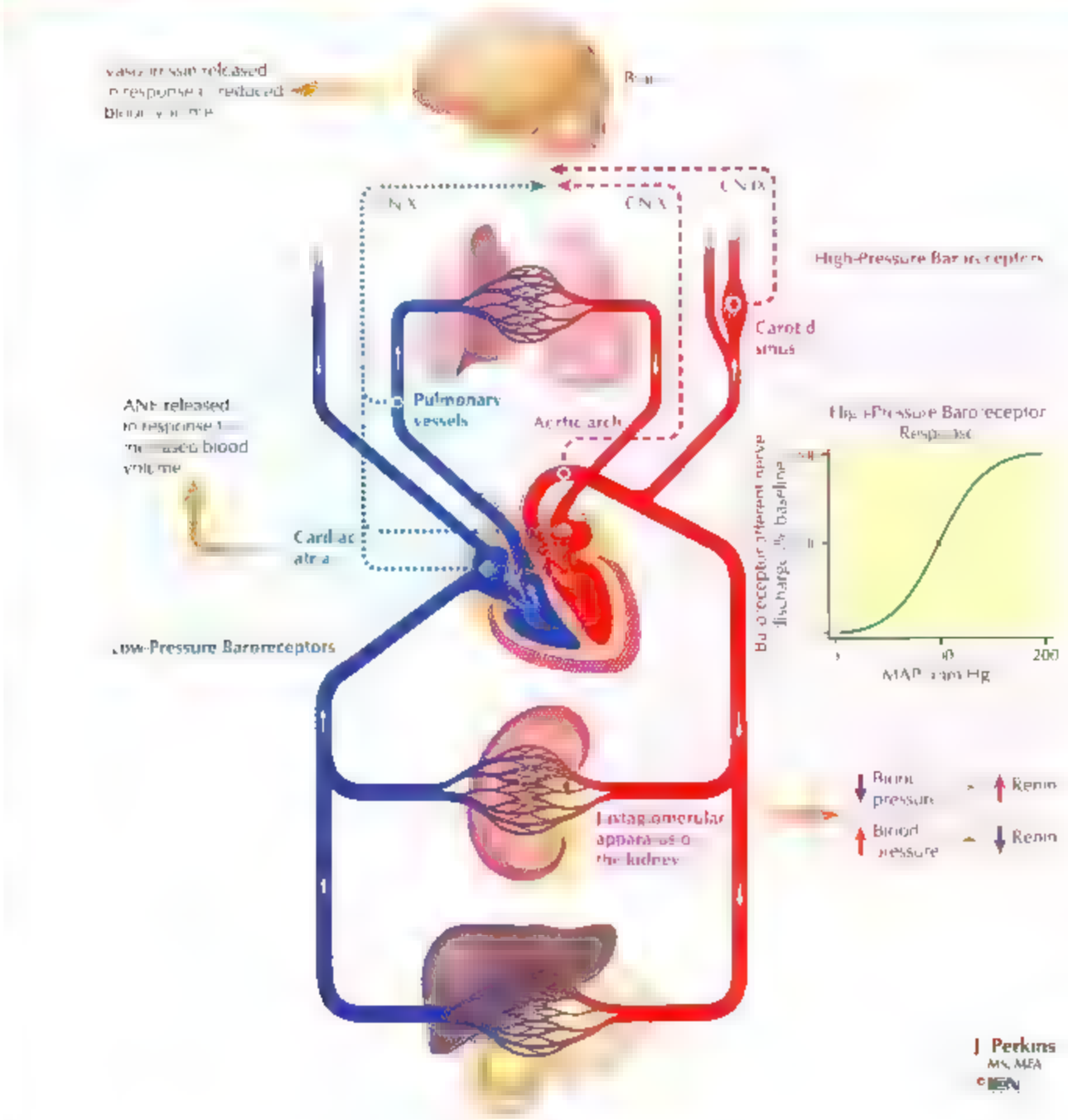


FIGURE 4.18 MONITORING OF BLOOD PRESSURE

...the cardiovascular system to maintain and regulate blood pressure... The system is critically important for the maintenance of BP during ...activity (e.g., rising from a sitting to a standing position or ...exercise), as well as during abnormal conditions (e.g., excessive ...in a hot environment or hemorrhage). Pressure sensors ...receptors, are located in the high-pressure (arterial) and ...pressure venous sides of the cardiovascular system. High-pressure ...receptors in the aortic arch and carotid sinuses monitor arterial BP ...and signals in the brainstem in the vagus (CN X) and glossopharyngeal (CN IX) nerves. These signals result in alterations in sympathetic ...activity (not shown). The afferent arterioles of the juxtaglomerular ...are also high-pressure baroreceptors. They respond to changes in arterial BP by varying the secretion of the proteolytic enzyme renin. As described in Figure 6.12, renin results in the production of angiotensin II, a potent vasoconstrictor (see Figure 4.15). Low-pressure baroreceptors are found in the large pulmonary vessels and the atria of the heart. By their location, they respond primarily to changes in blood volume. These baroreceptors send signals to the brainstem via vagus nerve (CN X), which, in addition to altering sympathetic nerve activity, causes release of vasopressin (ADH). When stretched (i.e., increased blood volume), the atria also secrete the hormone atrial natriuretic peptide (ANP), which promotes the excretion of NaCl and water by the kidneys (see Figure 4.20) and decreases arterial tone (see Figure 4.15).

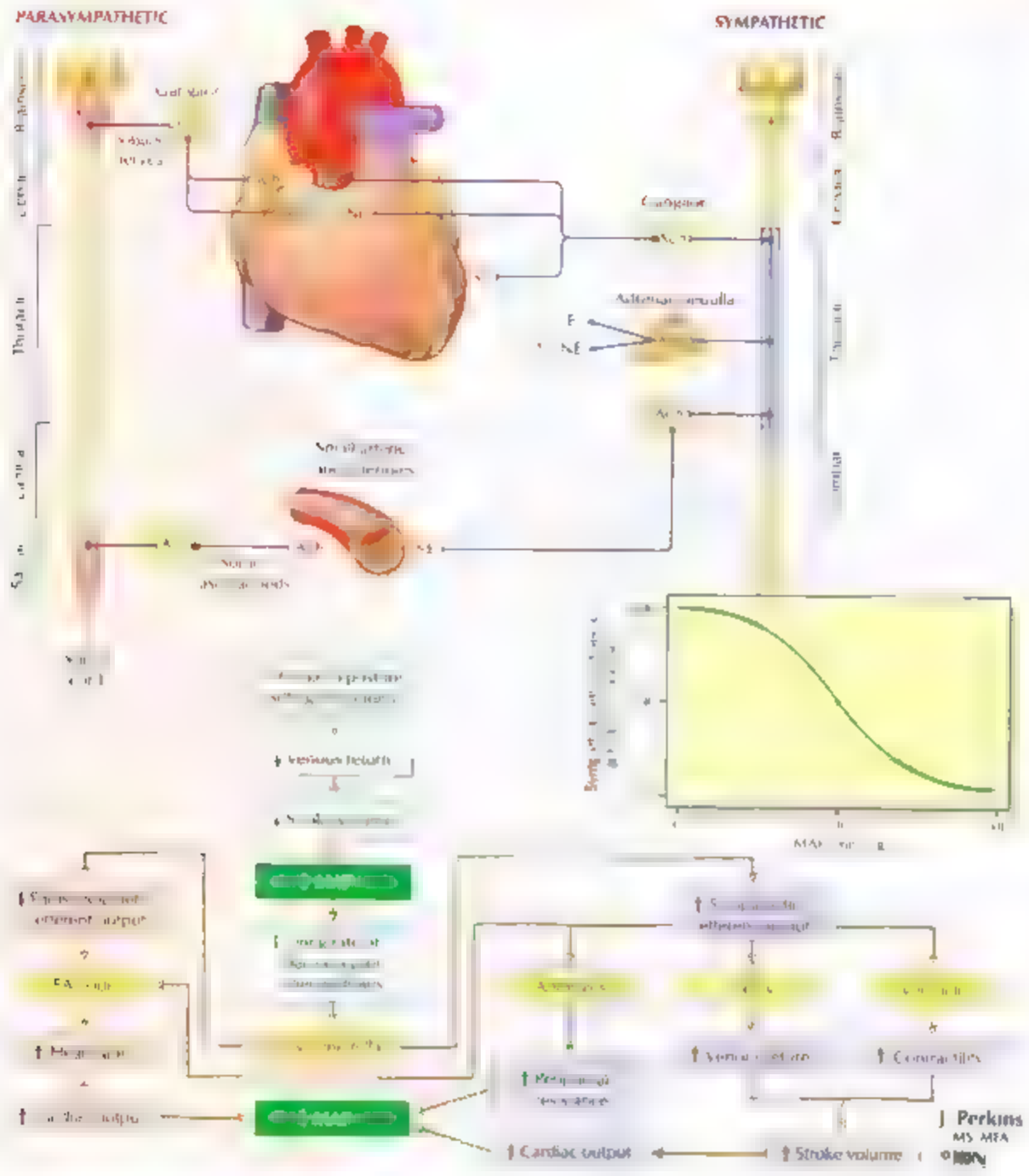


FIGURE 4.19 SHORT-TERM RESPONSE TO CHANGES IN BLOOD PRESSURE

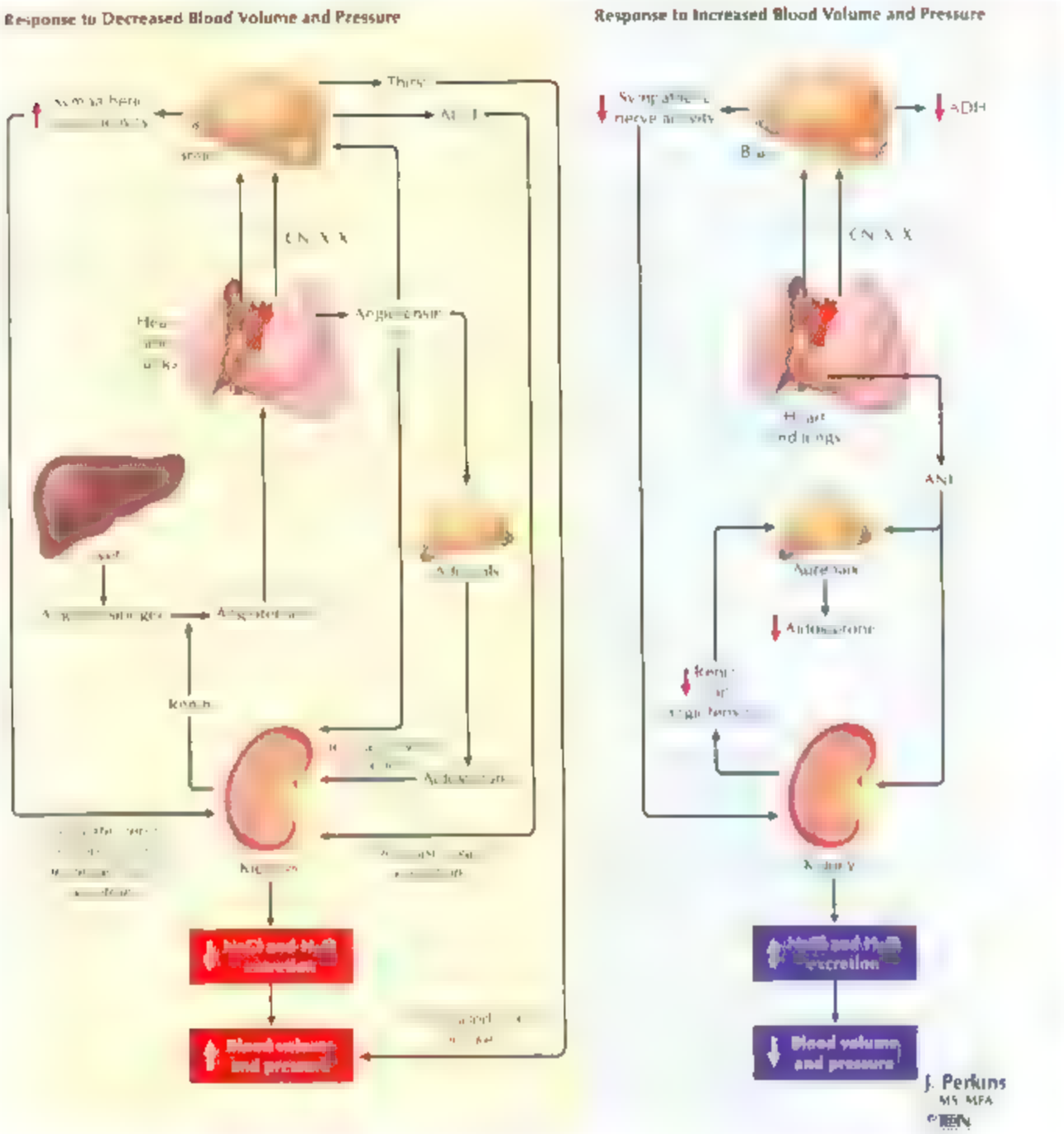


FIGURE 4.20 LONG-TERM RESPONSE TO CHANGES IN BLOOD VOLUME AND PRESSURE

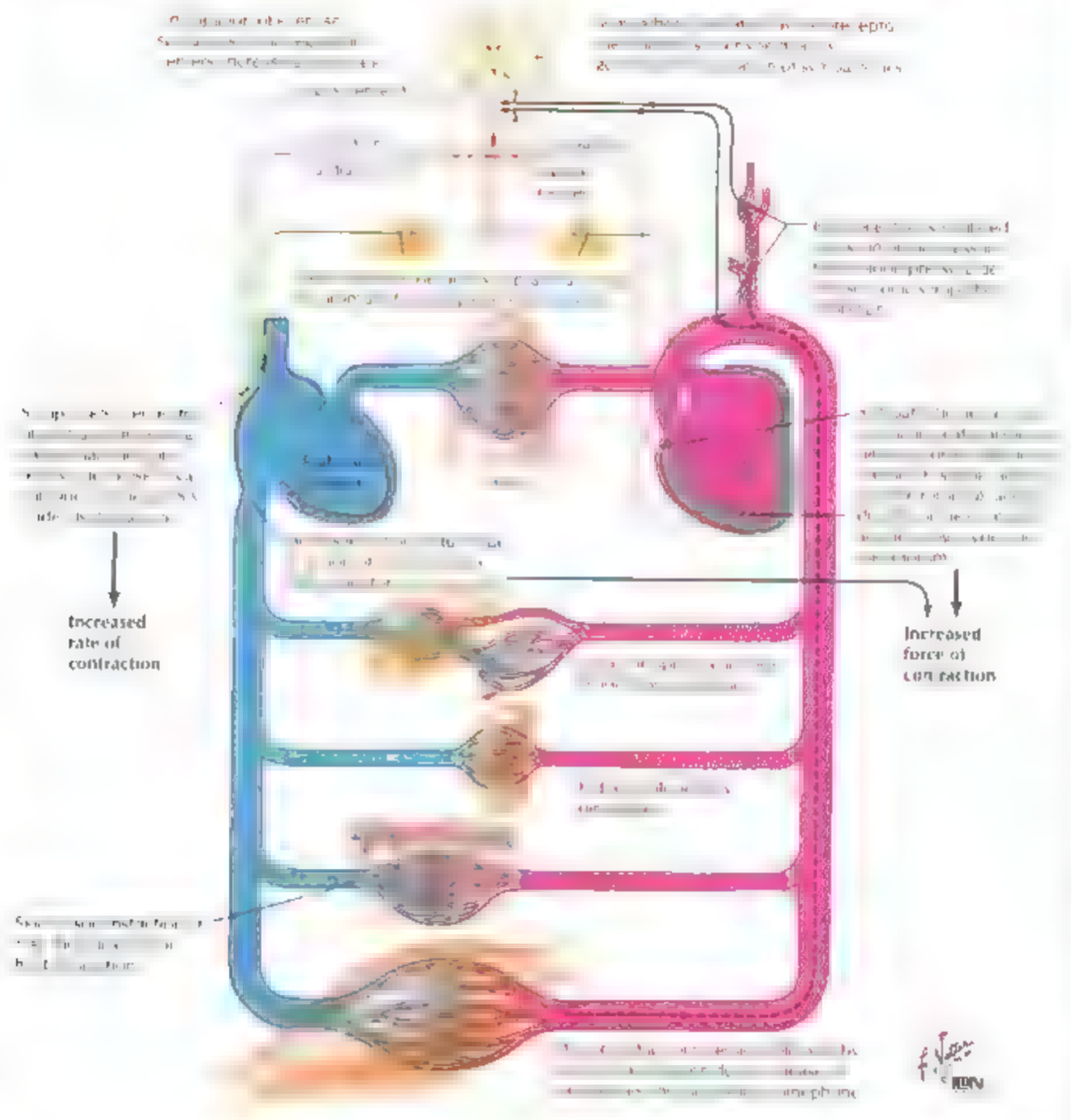


FIGURE 4.21 CIRCULATORY RESPONSE TO EXERCISE

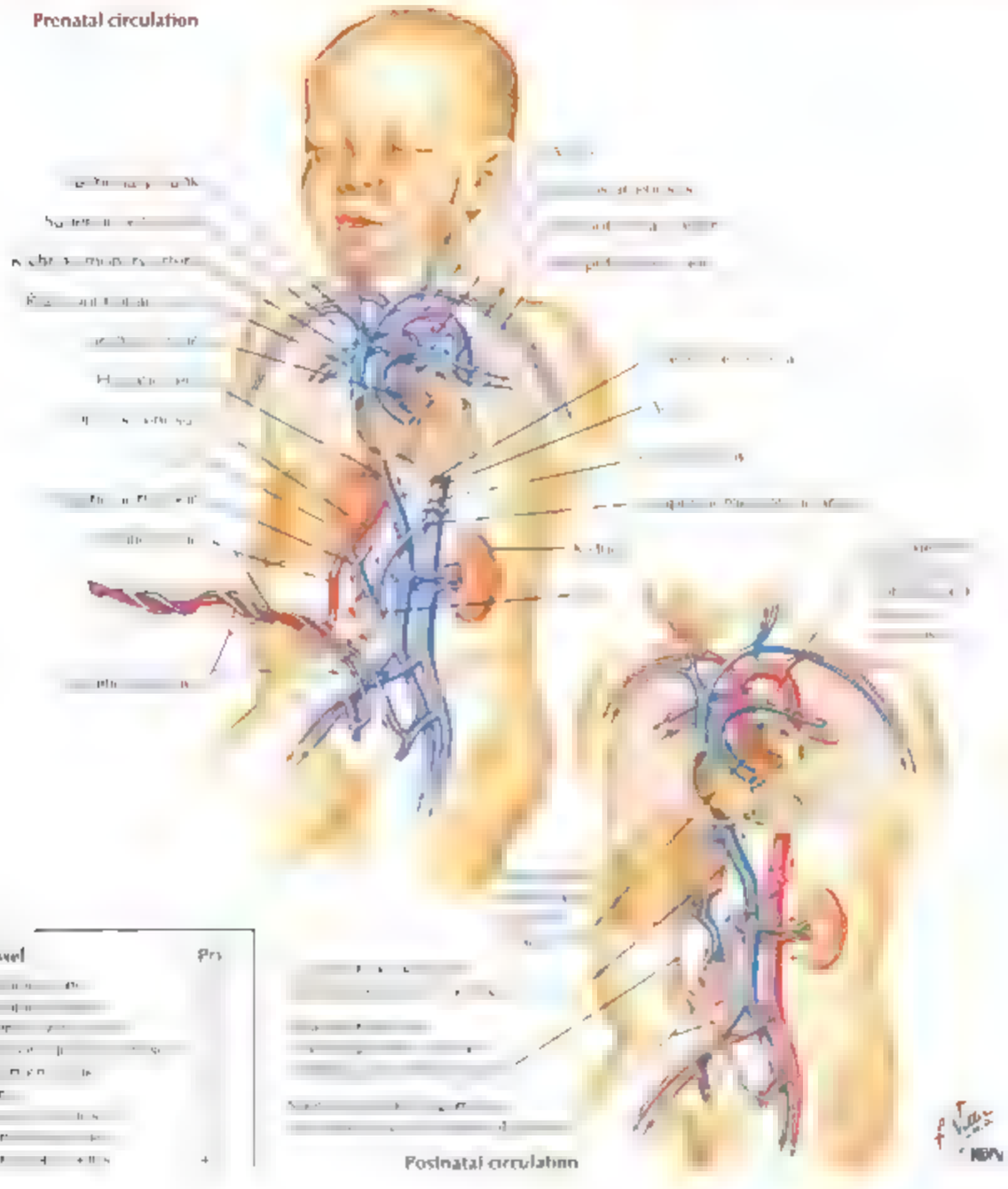


FIGURE 4.22 PRENATAL AND POSTNATAL CIRCULATION

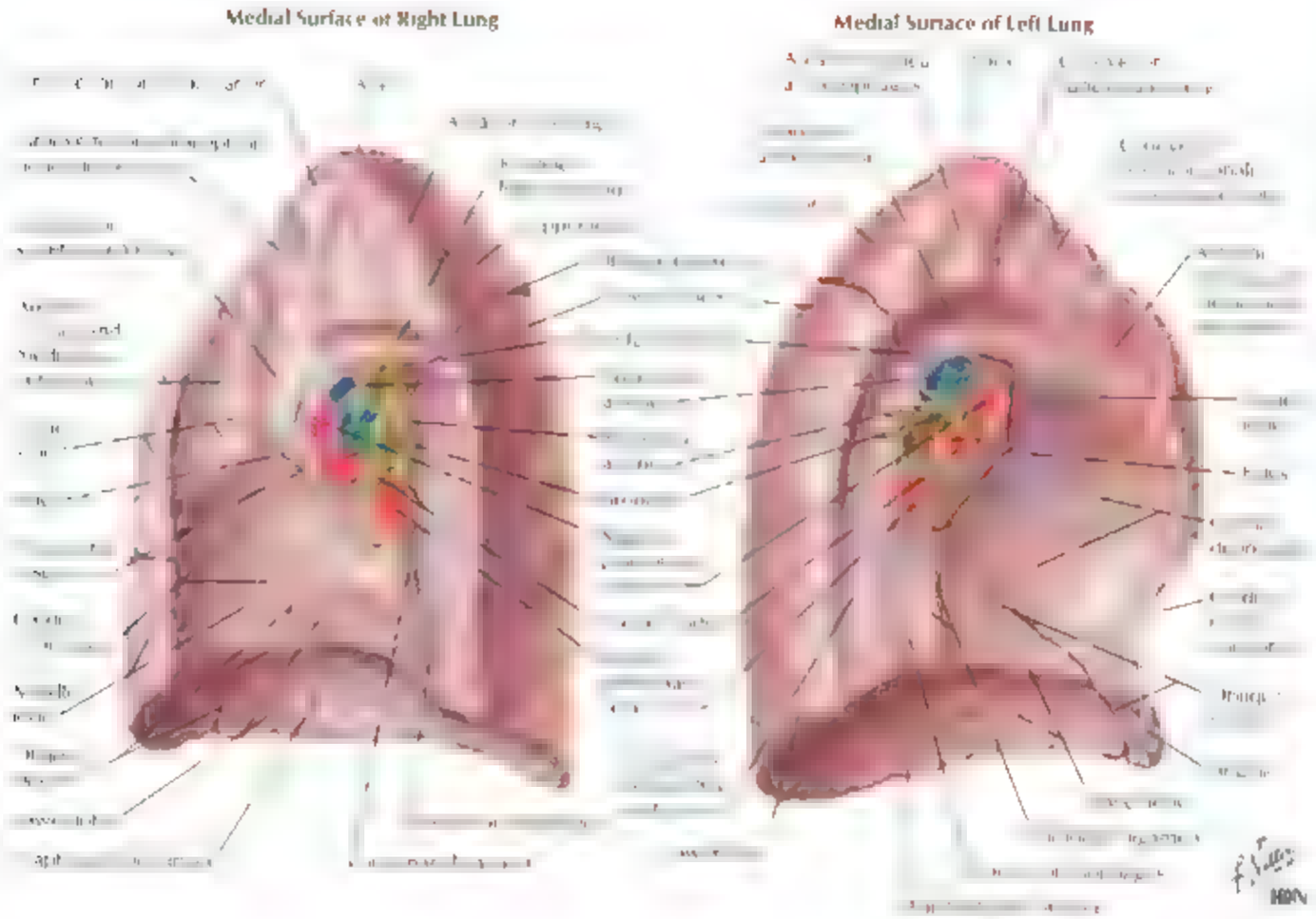


FIGURE 5.1 MEDIAL SURFACE OF THE LUNGS

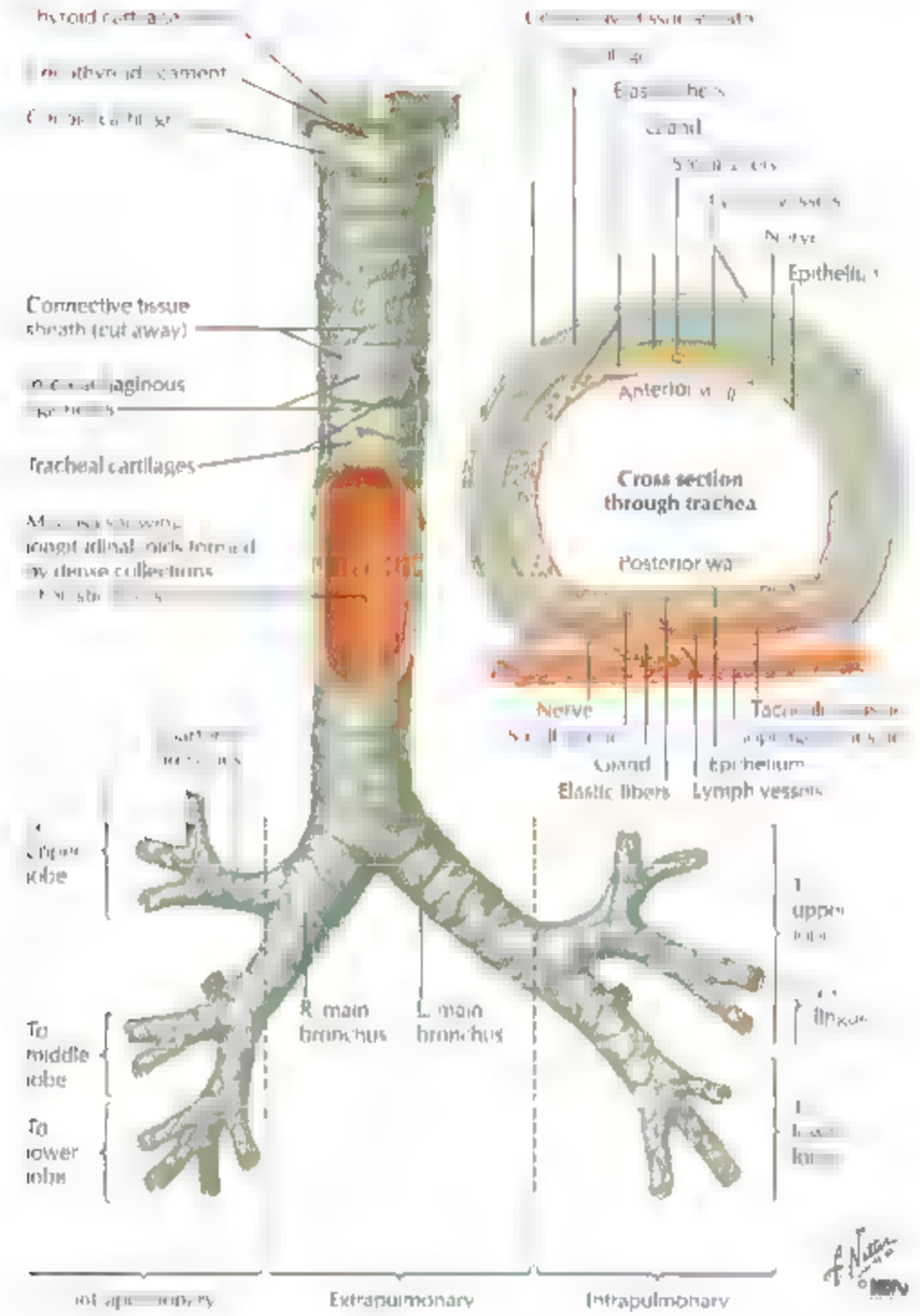


FIGURE 5.2 STRUCTURE OF THE TRACHEA AND MAJOR BRONCHI

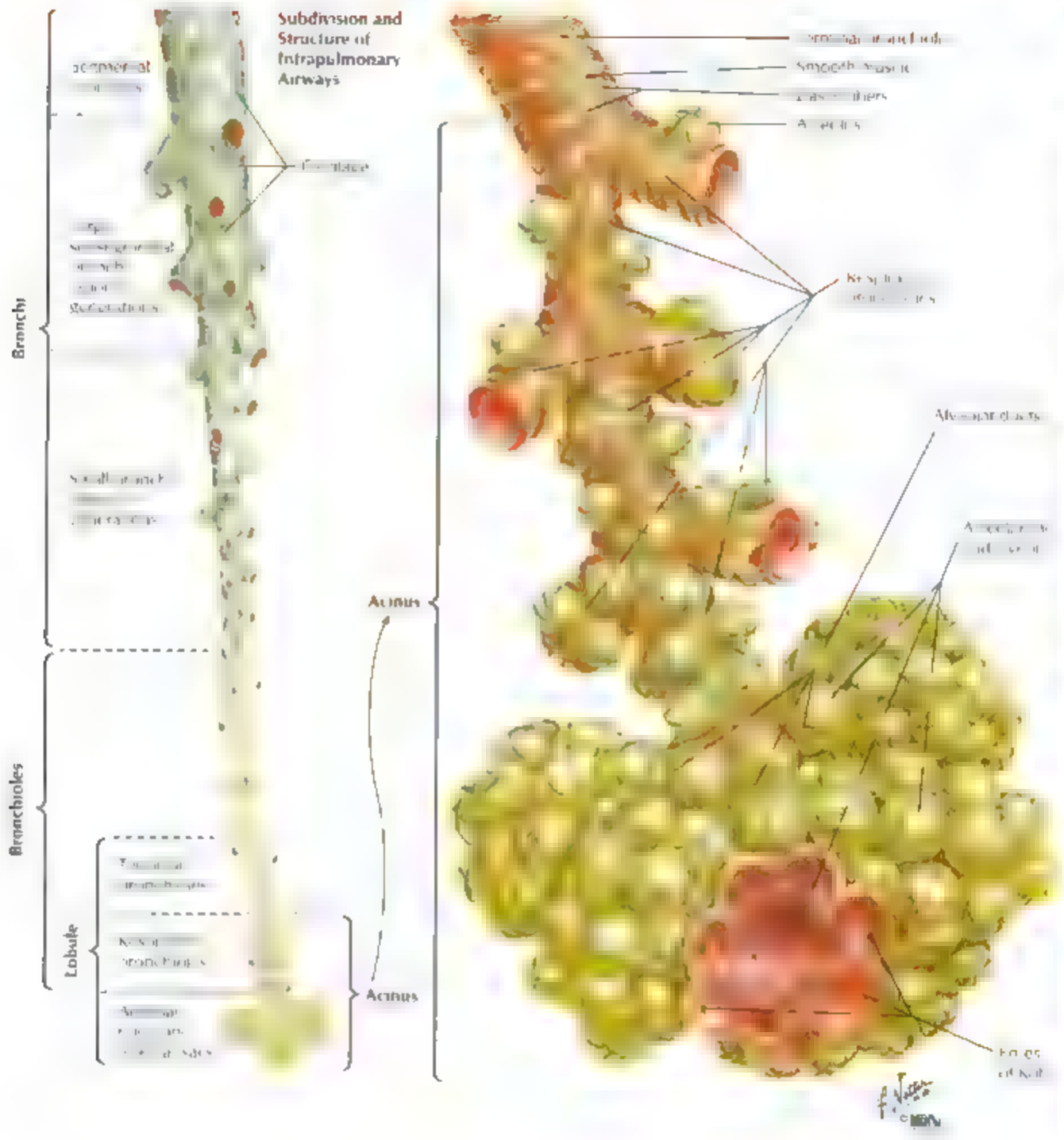
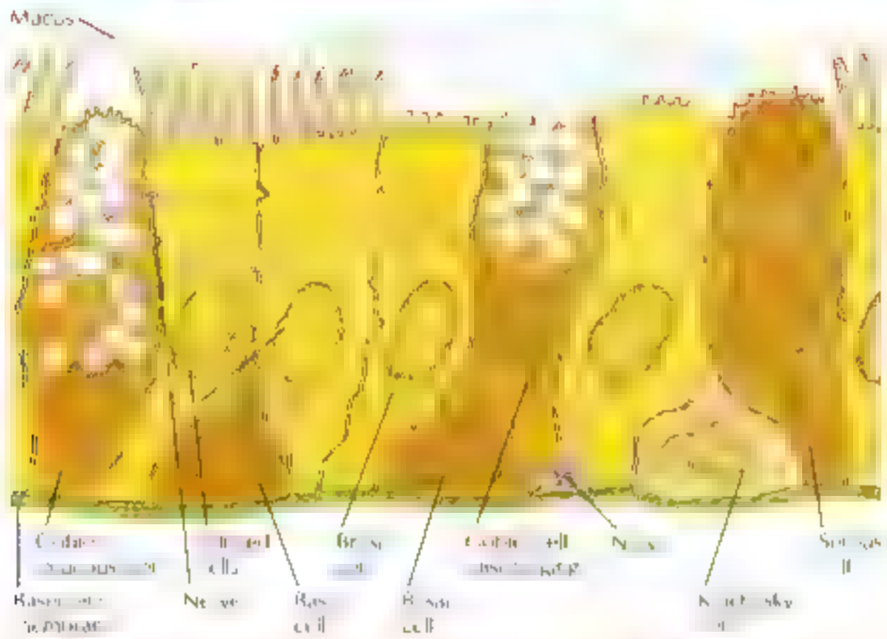
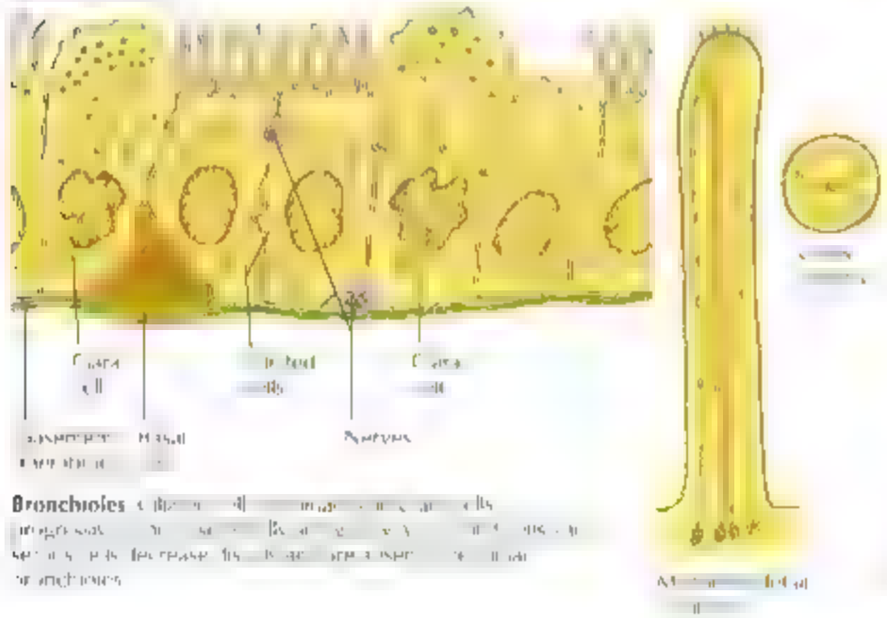


FIGURE 5.3 INTRAPULMONARY AIRWAYS

As air passes through the intrapulmonary airways, it passes through a series of [illegible] alveoli. The respiratory bronchioles are lined with alveolar [illegible] representing the respiratory zone.



Trachea and large bronchi



Bronchioles

FIGURE 5.4 ULTRASTRUCTURE OF TRACHEAL, BRONCHIAL, AND BRONCHIOLAR EPITHELIUM

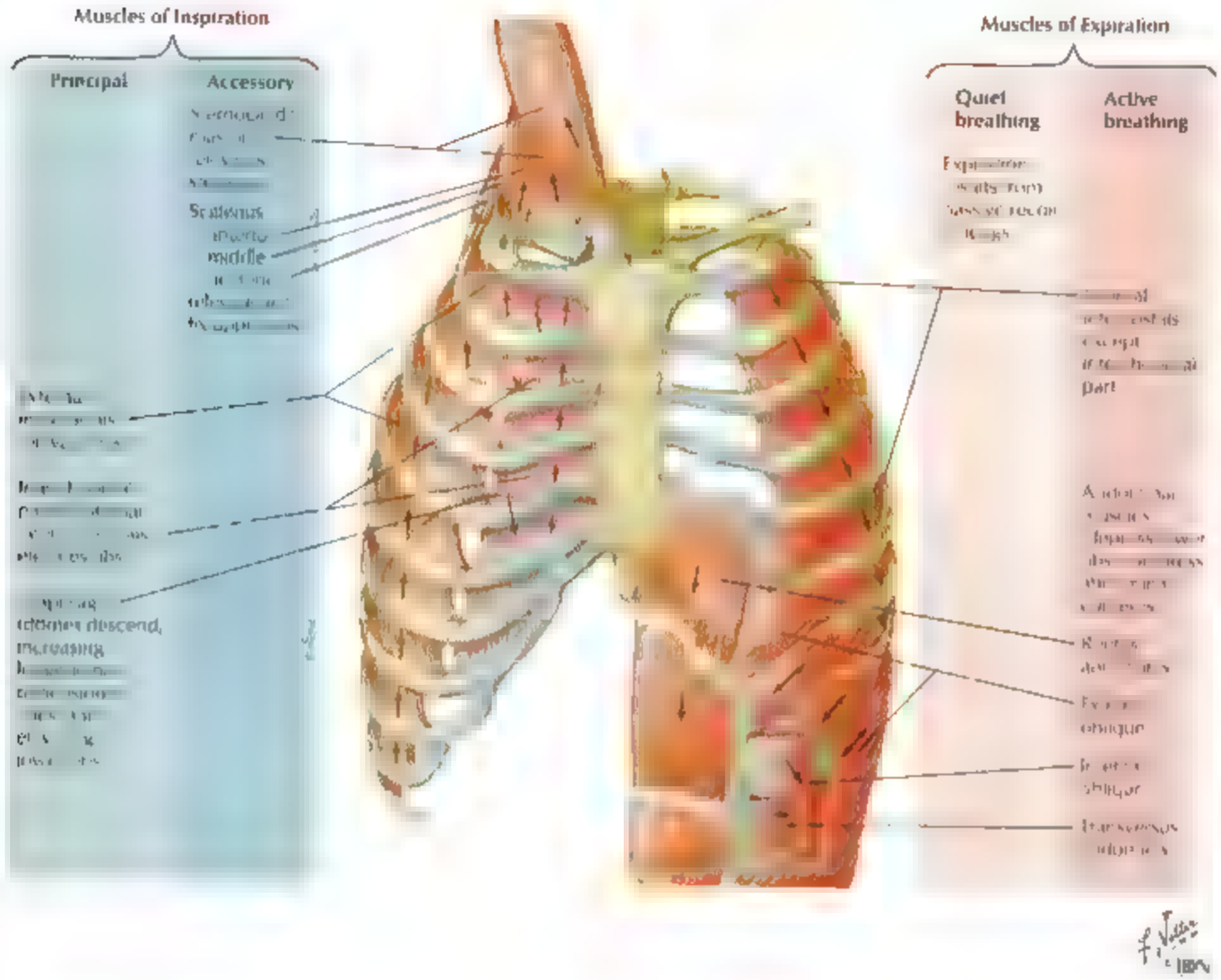


FIGURE 5.5 RESPIRATORY MUSCLES

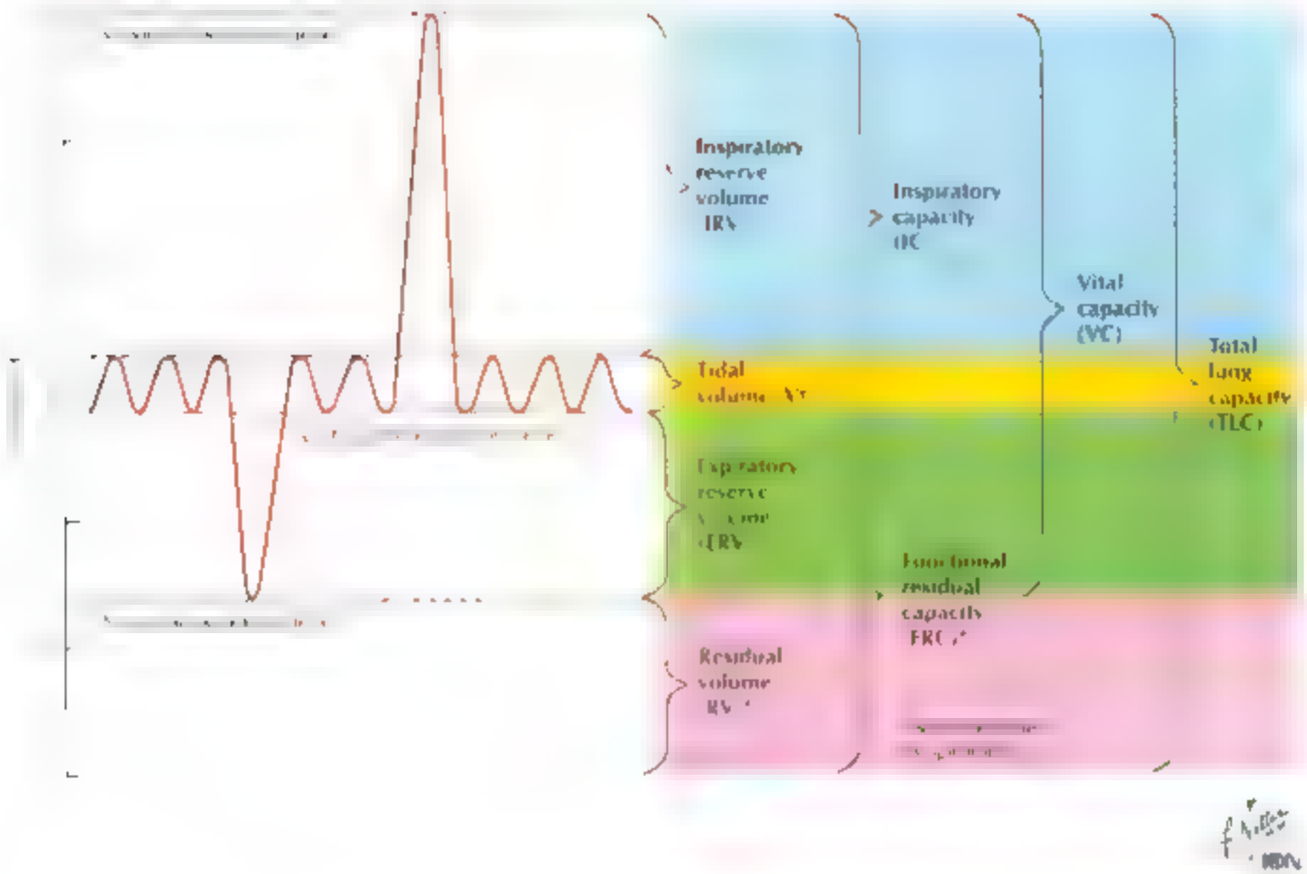


FIGURE 5.6 SPIROMETRY

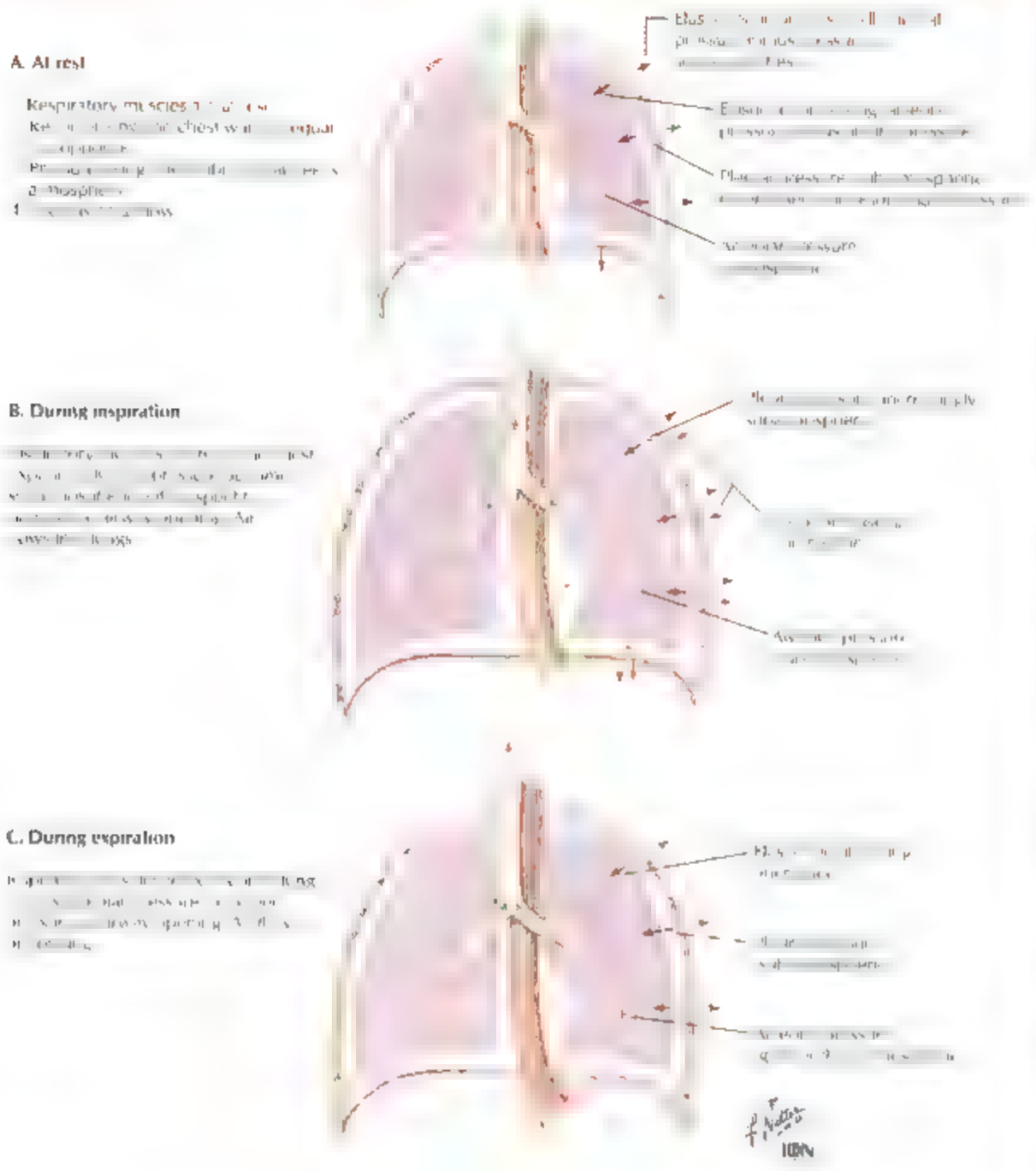
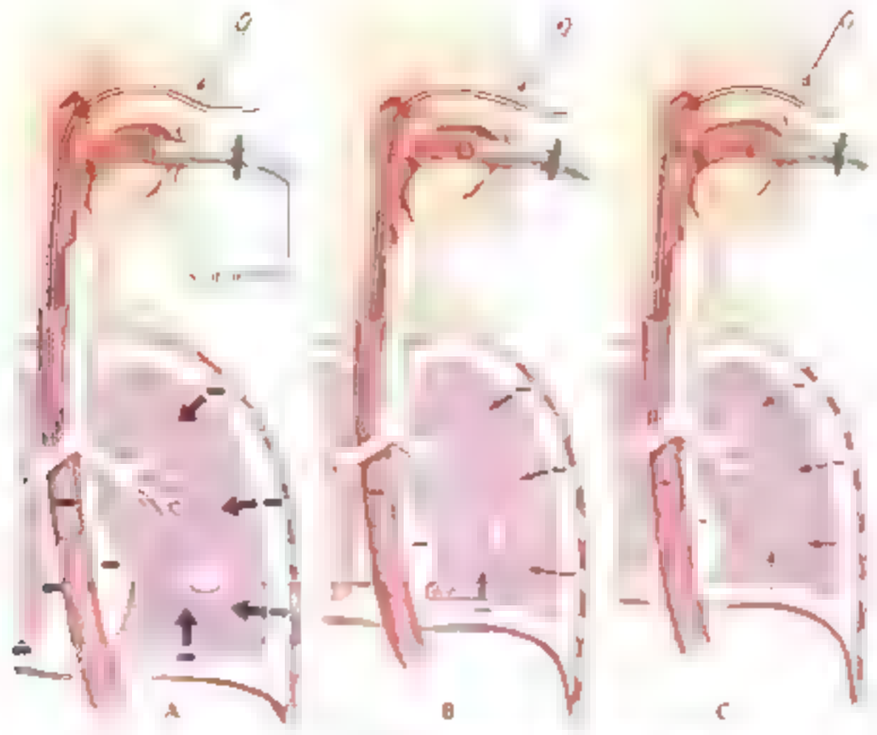


FIGURE 5.7 FORCES DURING QUIET BREATHING



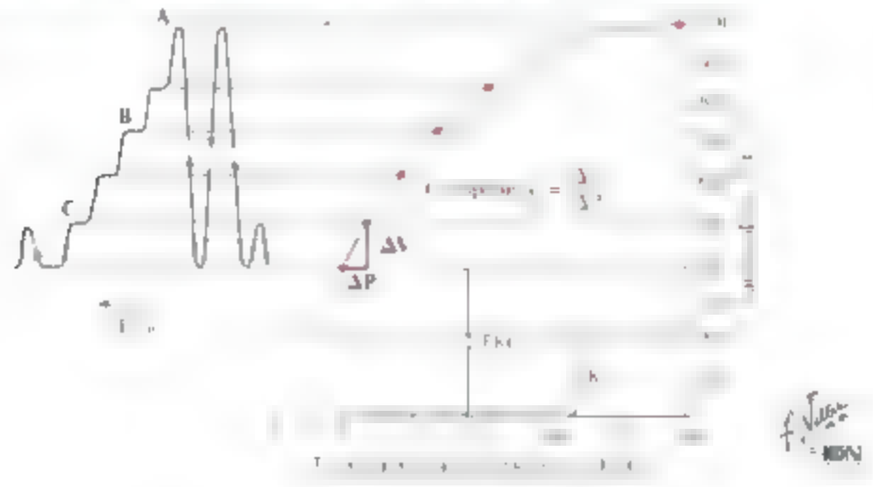


FIGURE 5.8 MEASUREMENT OF ELASTIC PROPERTIES OF LUNG

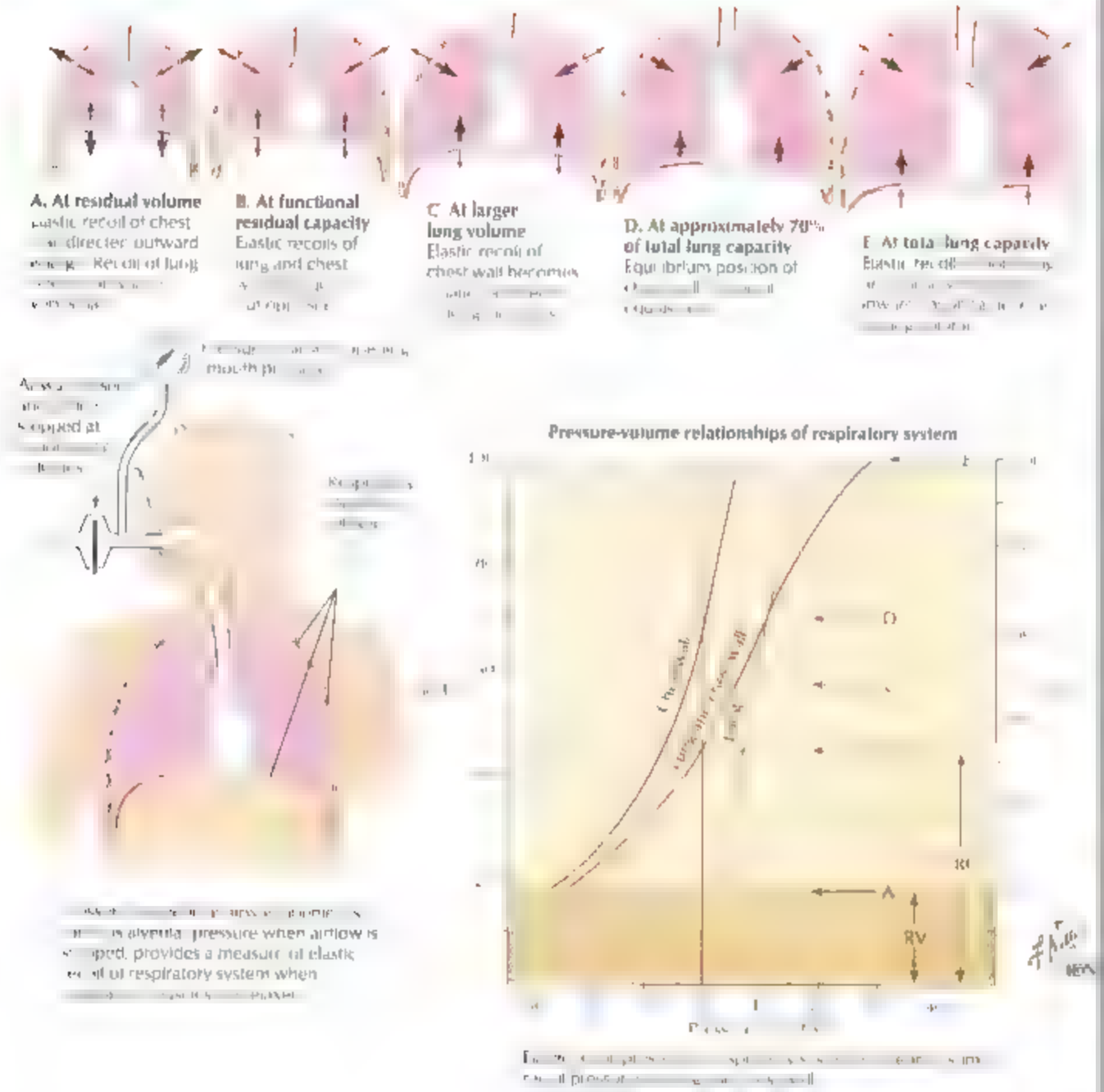
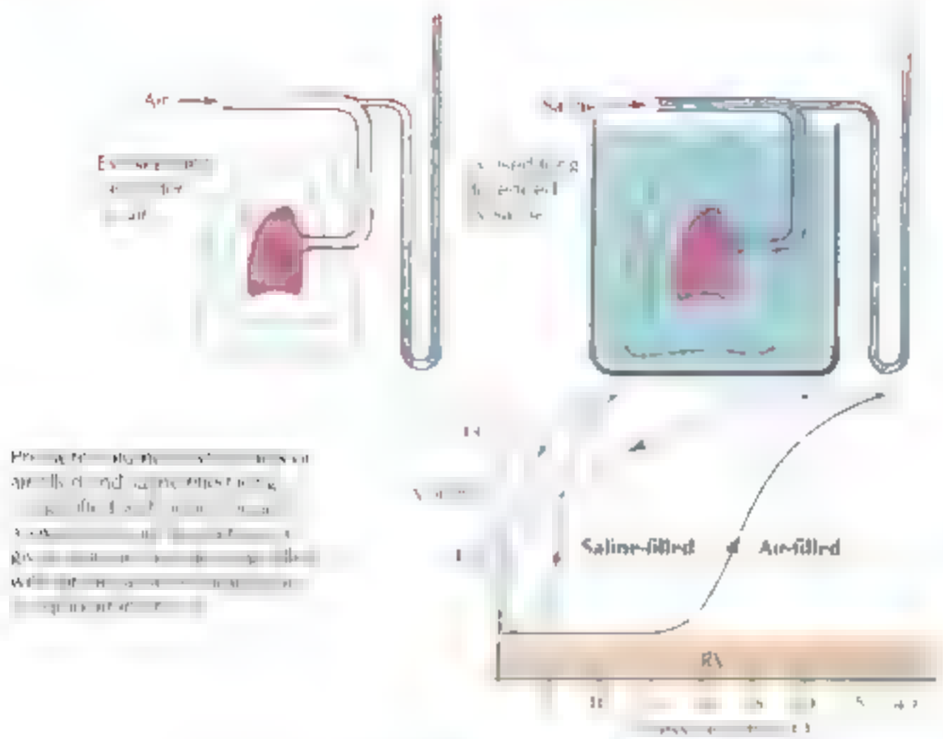
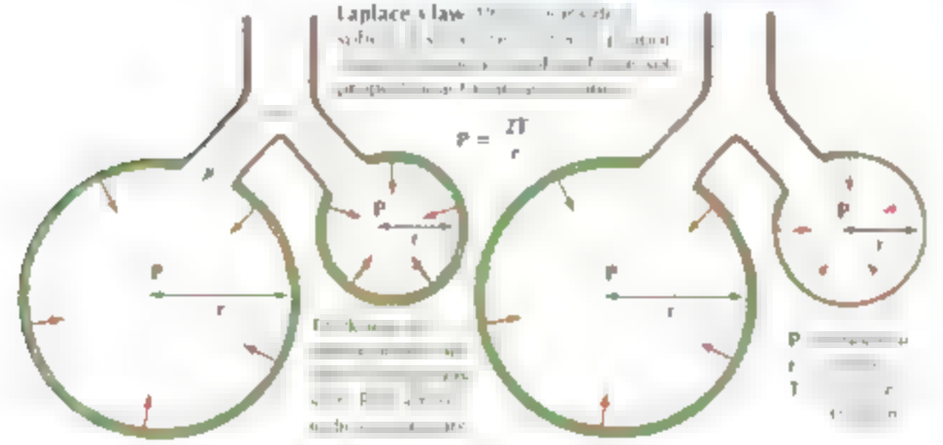


FIGURE 5.9 ELASTIC PROPERTIES OF RESPIRATORY SYSTEM: LUNG AND CHEST WALL

The elastic recoil or compliance properties of the lungs and chest wall alone and combined are shown diagrammatically and graphically.





Without surfactant.

With surfactant

FIGURE 5.10 SURFACE FORCES IN THE LUNG.

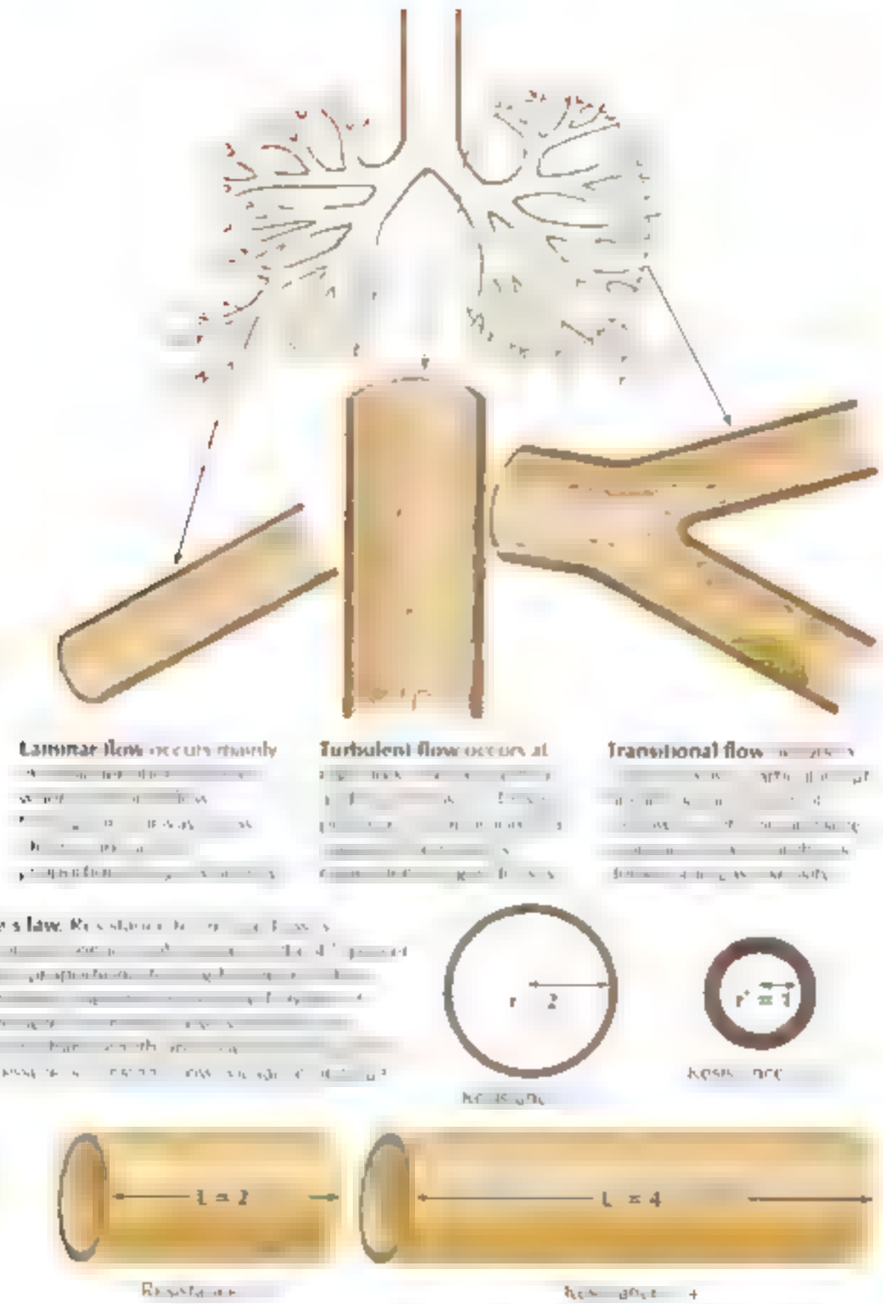
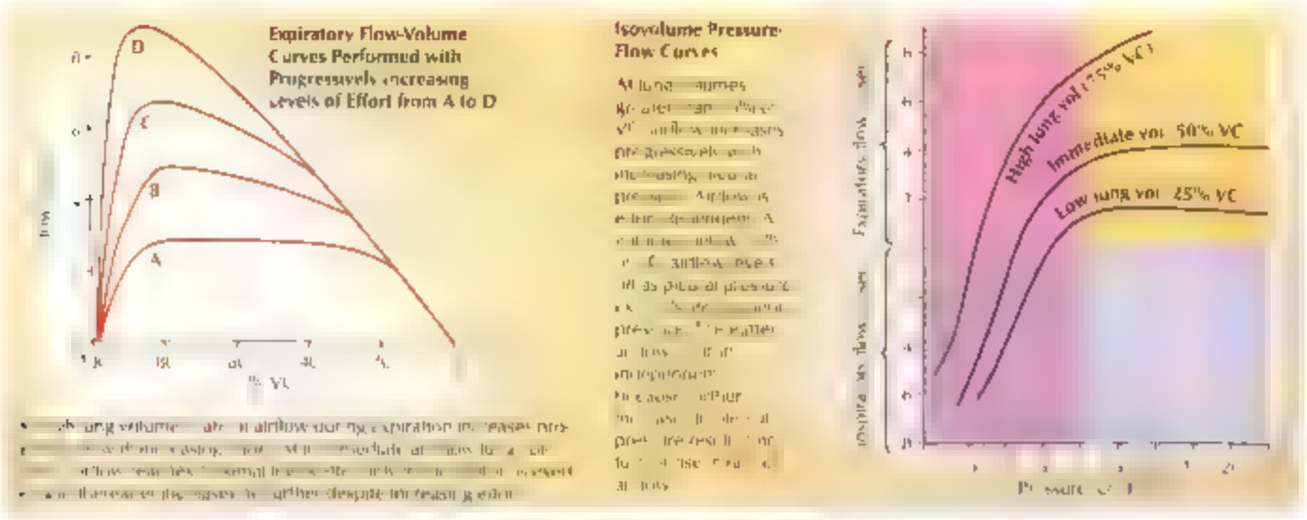


FIGURE 5.11 AIRWAY FLOW

Airflow through the respiratory system is ... flow ... regions of the respiratory system ... resistance ... radius



Determinants of Maximal Expiratory Flow

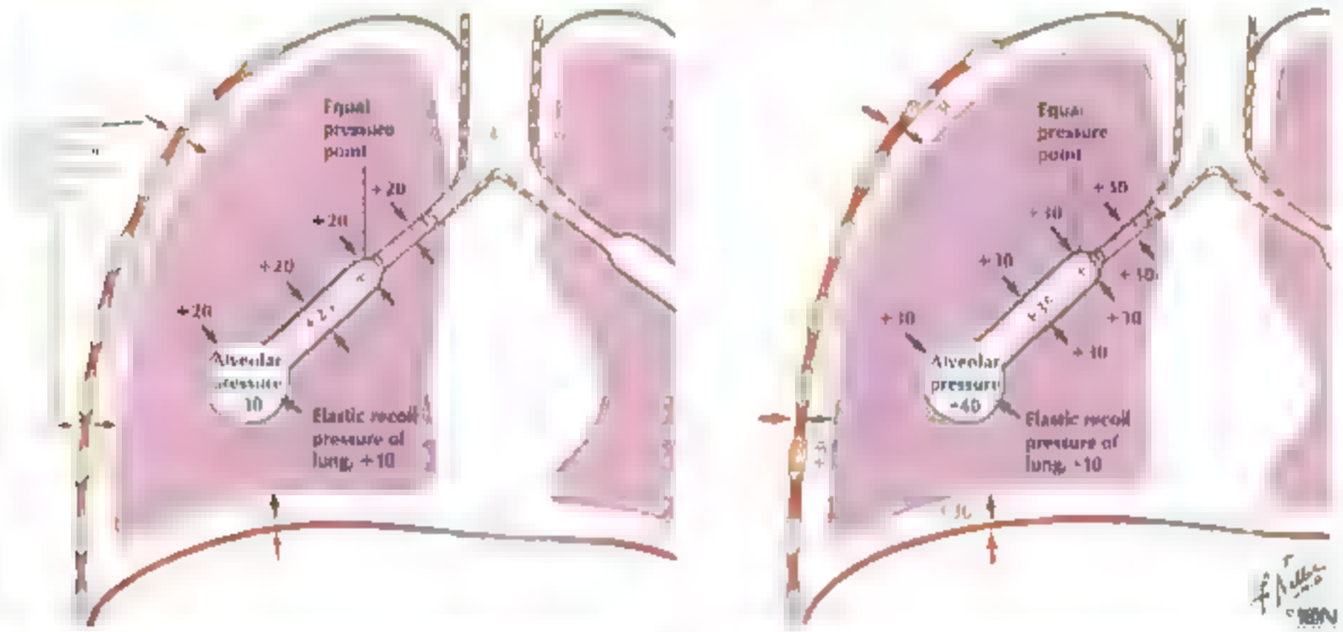


FIGURE 5.12 FLOW-VOLUME RELATIONSHIPS

...w varies as a function of pressure and lung volume. The highest rates of airflow are seen at high lung volumes

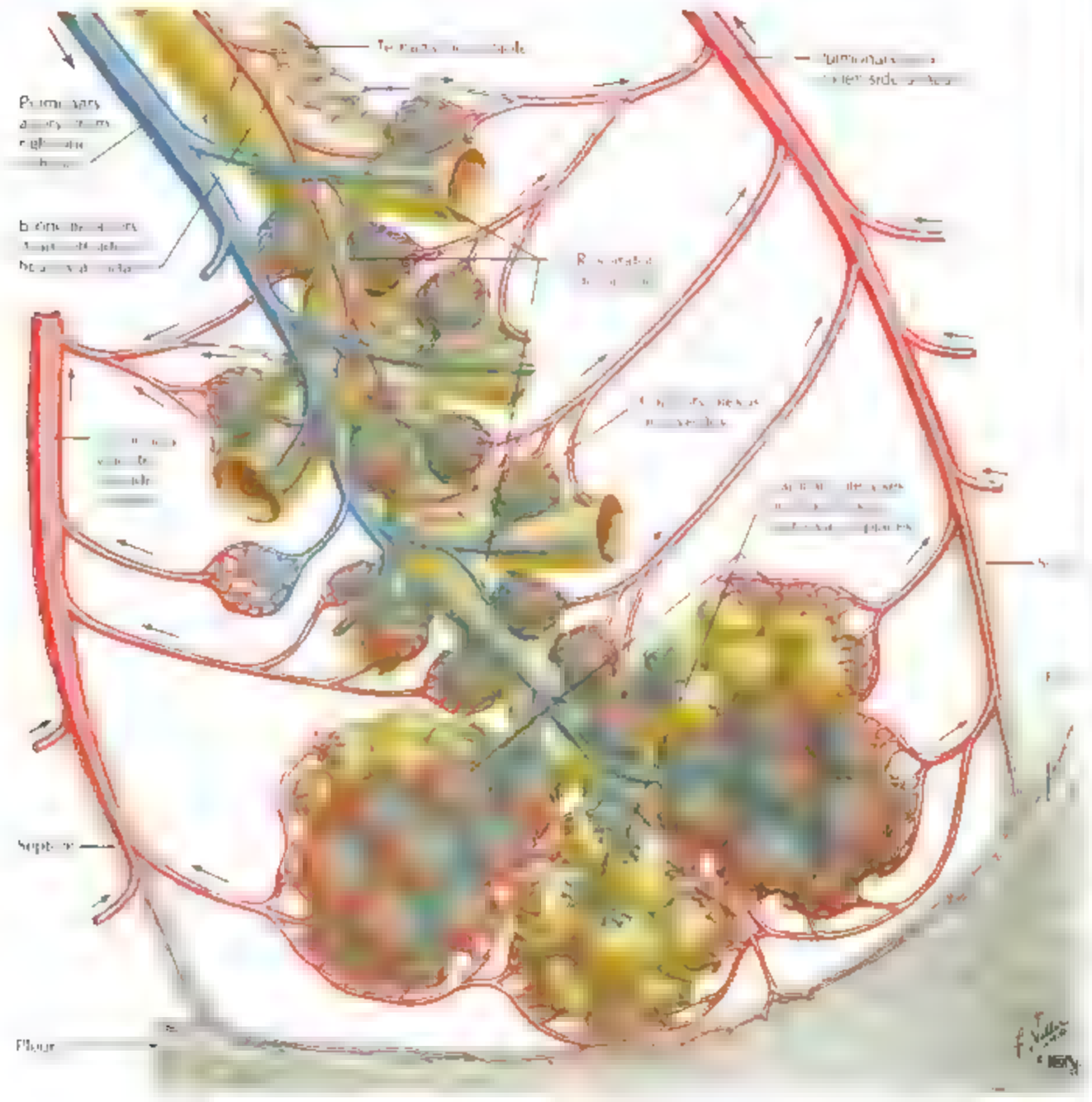


FIGURE 5-13 INTRAPULMONARY BLOOD CIRCULATION

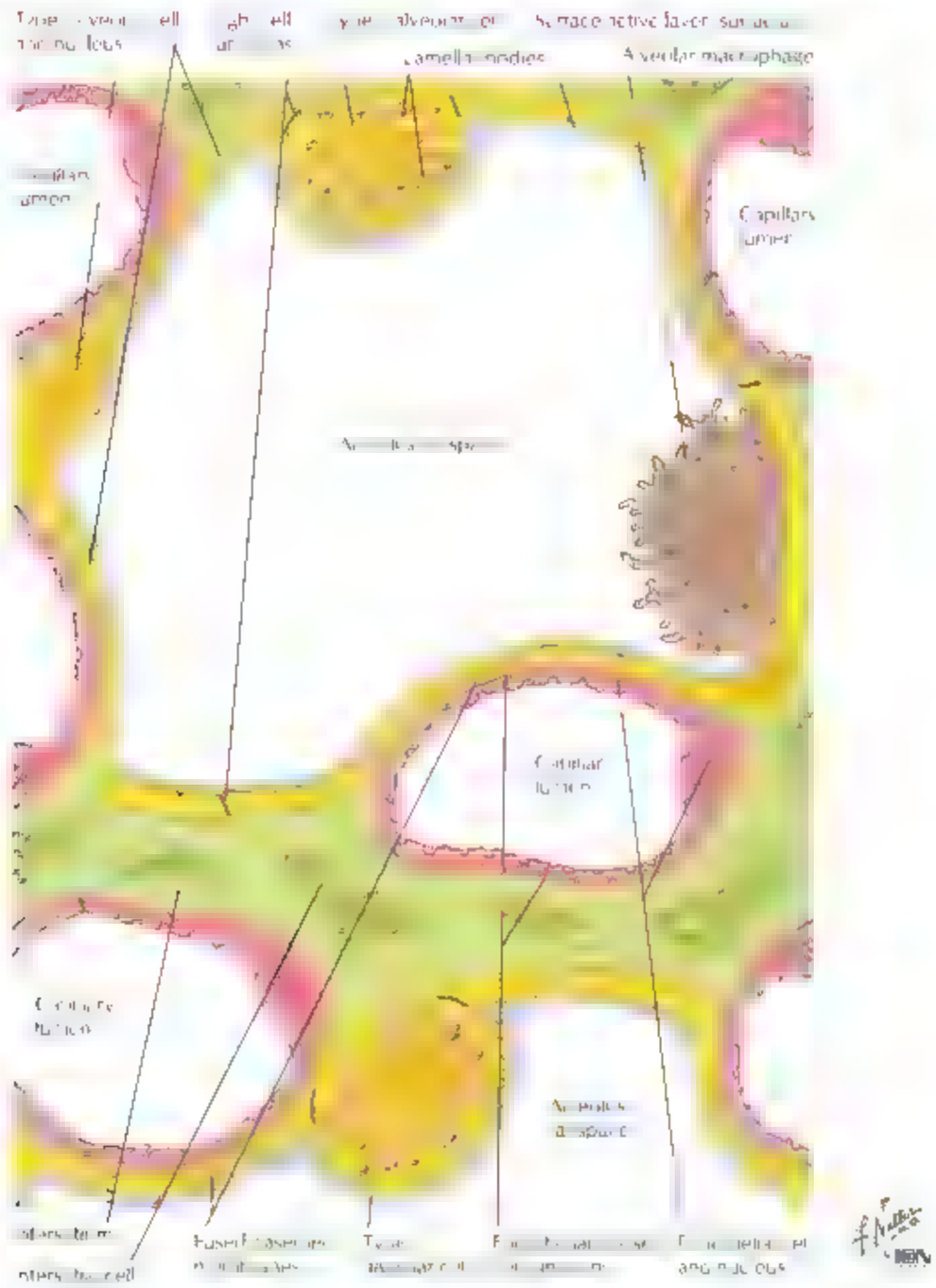


FIGURE 5.14 ULTRASTRUCTURE OF PULMONARY ALVEOLI AND CAPILLARIES

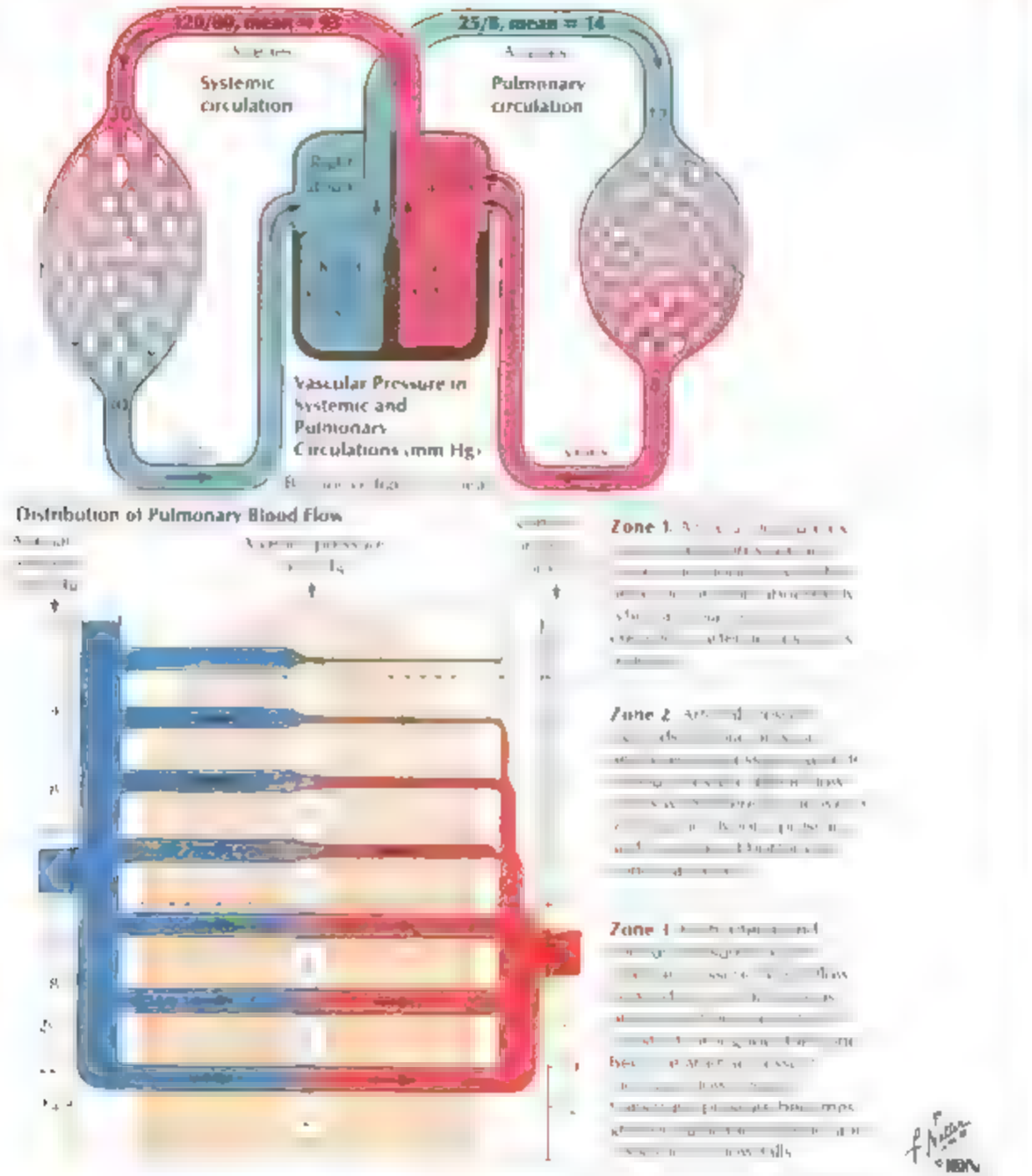


FIGURE 5.15 PULMONARY CIRCULATION

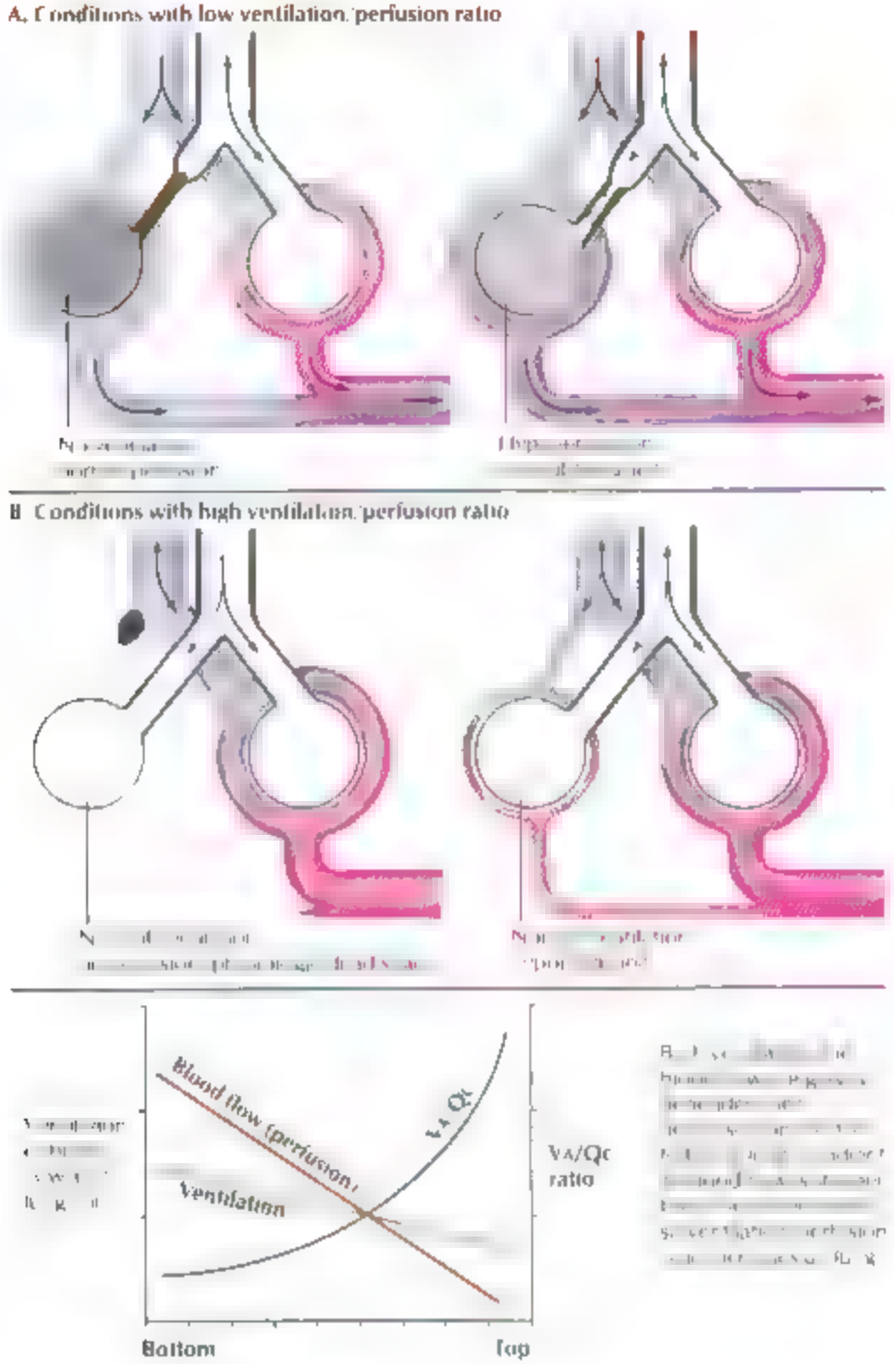


FIGURE 5-16 VENTILATION/PERFUSION (V_A/Q_C) RELATIONSHIPS

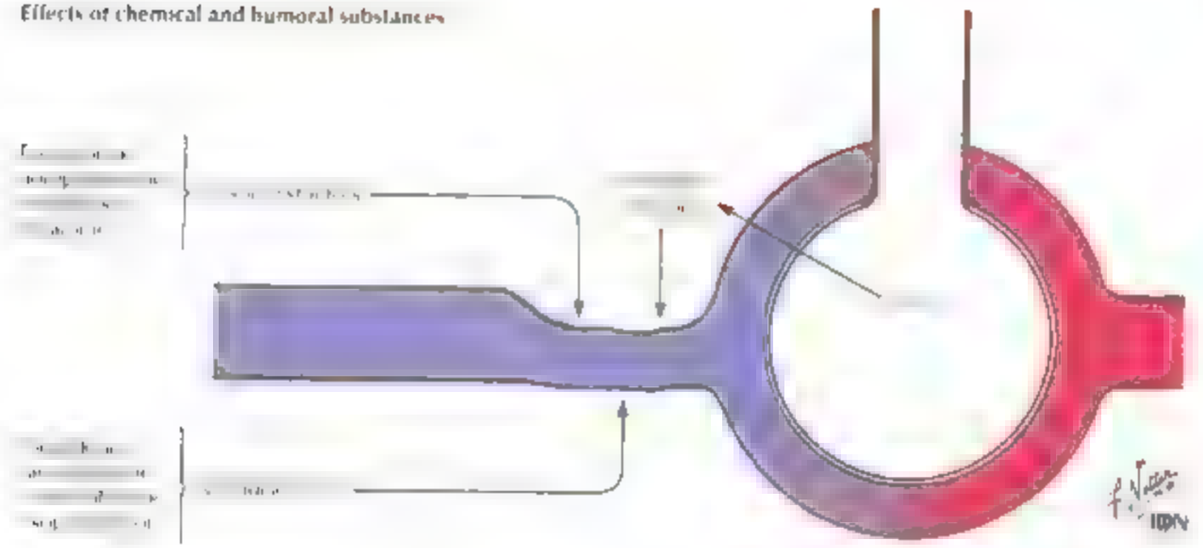


FIGURE 5.17 PULMONARY VASCULAR RESISTANCE

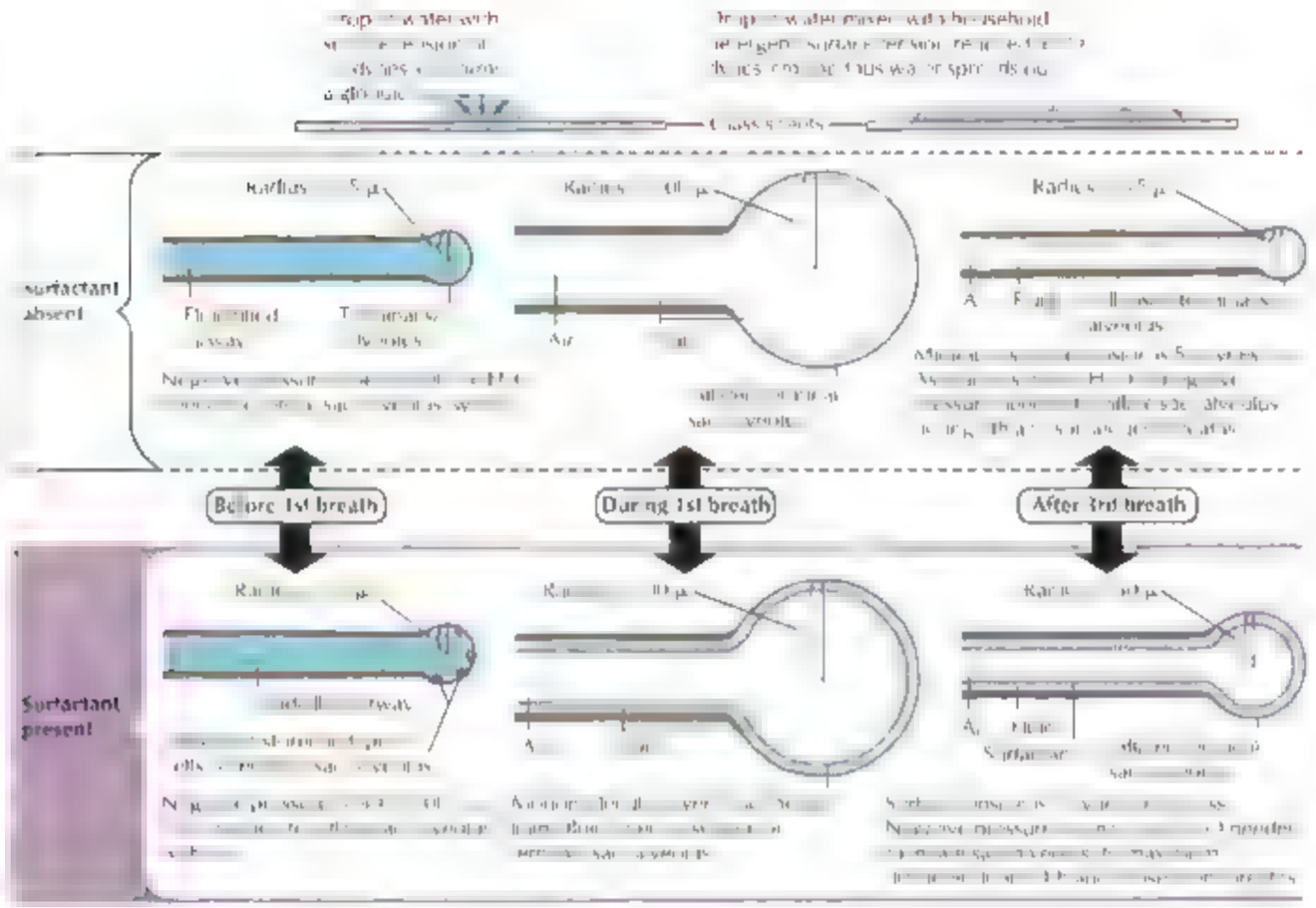


FIGURE 5.18 SURFACTANT EFFECTS

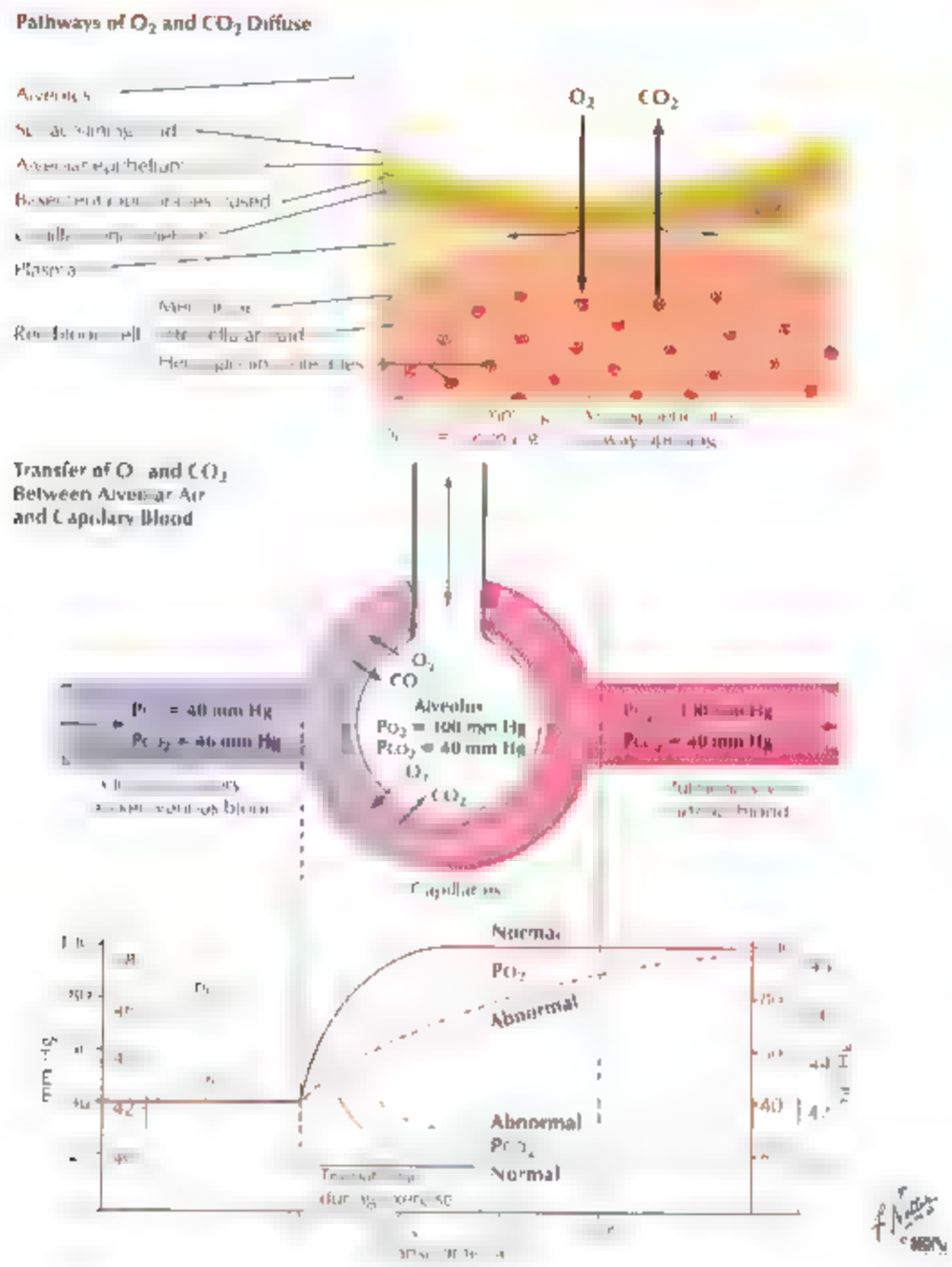


FIGURE 5.19 O_2 AND CO_2 EXCHANGE

As blood flows through the alveolar capillaries, O_2 diffuses from the alveolus into the blood and binds with hemoglobin. At the same time, CO_2 diffuses out of the blood into the alveolus. Normally, blood remains in the capillary for about 0.75 second, which is more than enough time for the gases to reach equilibrium. Full equilibration of blood with alveolar gases requires only about 0.25 second. Thus, even with a fivefold increase in blood flow, there is enough time for adequate gas exchange. Diffusion of gases across the alveolar capillary wall is rapid because the wall is very thin. Diffusion of gases is impaired if the wall thickens, as occurs with pulmonary edema, or if the surface area is reduced, as occurs with emphysema. Impairment of gas exchange is usually not significant at rest but may be significant during exercise. Blood leaving pulmonary capillaries with less than normal P_{O_2} is referred to as abnormal.

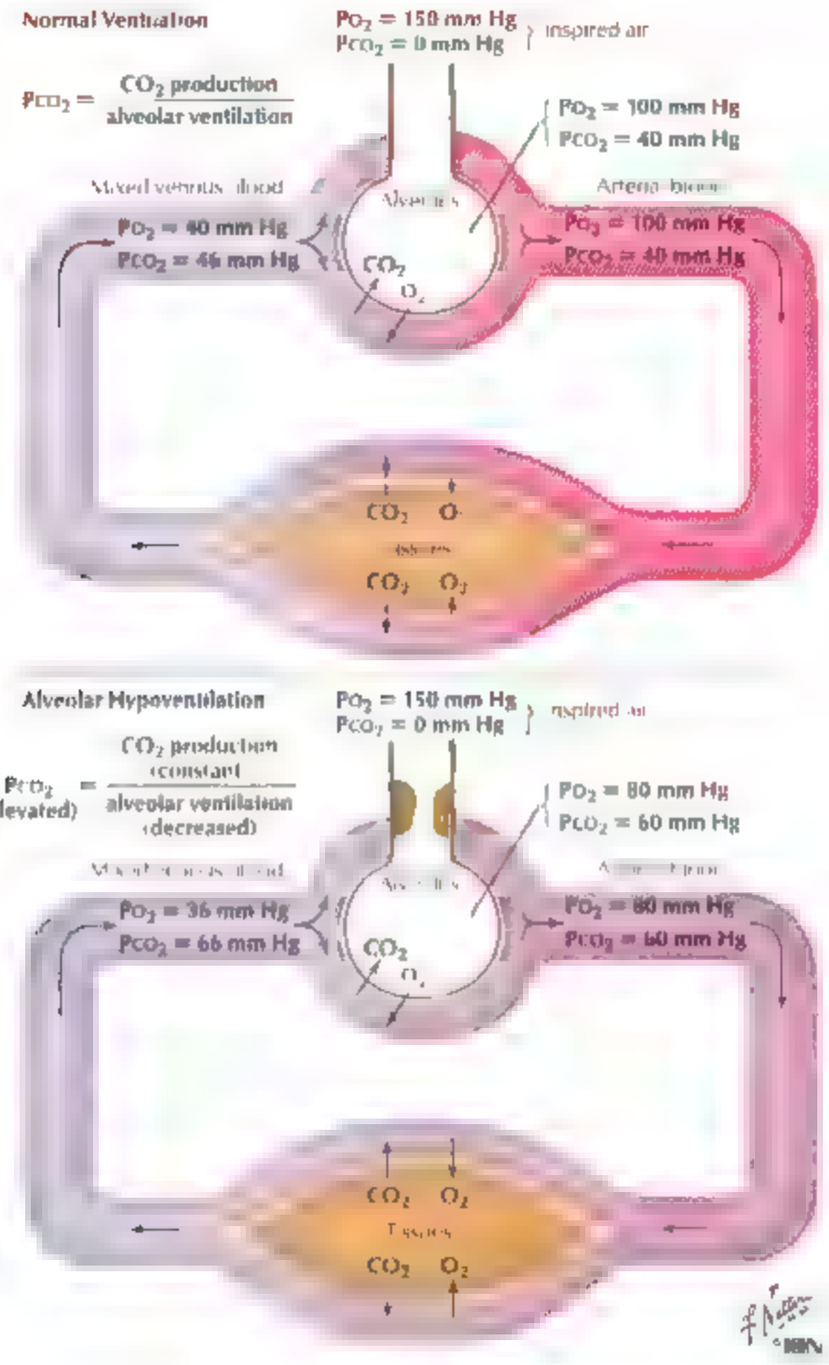


FIGURE 5.20 O_2 AND CO_2 EXCHANGE AND TRANSPORT

Hypoventilation is illustrated here as a partial blockage of the airway. Note the resulting changes in alveolar P_{O_2} and P_{CO_2}, as well as the arterial blood P_{O_2} (hypoxemia) and P_{CO_2} (hypercapnia).

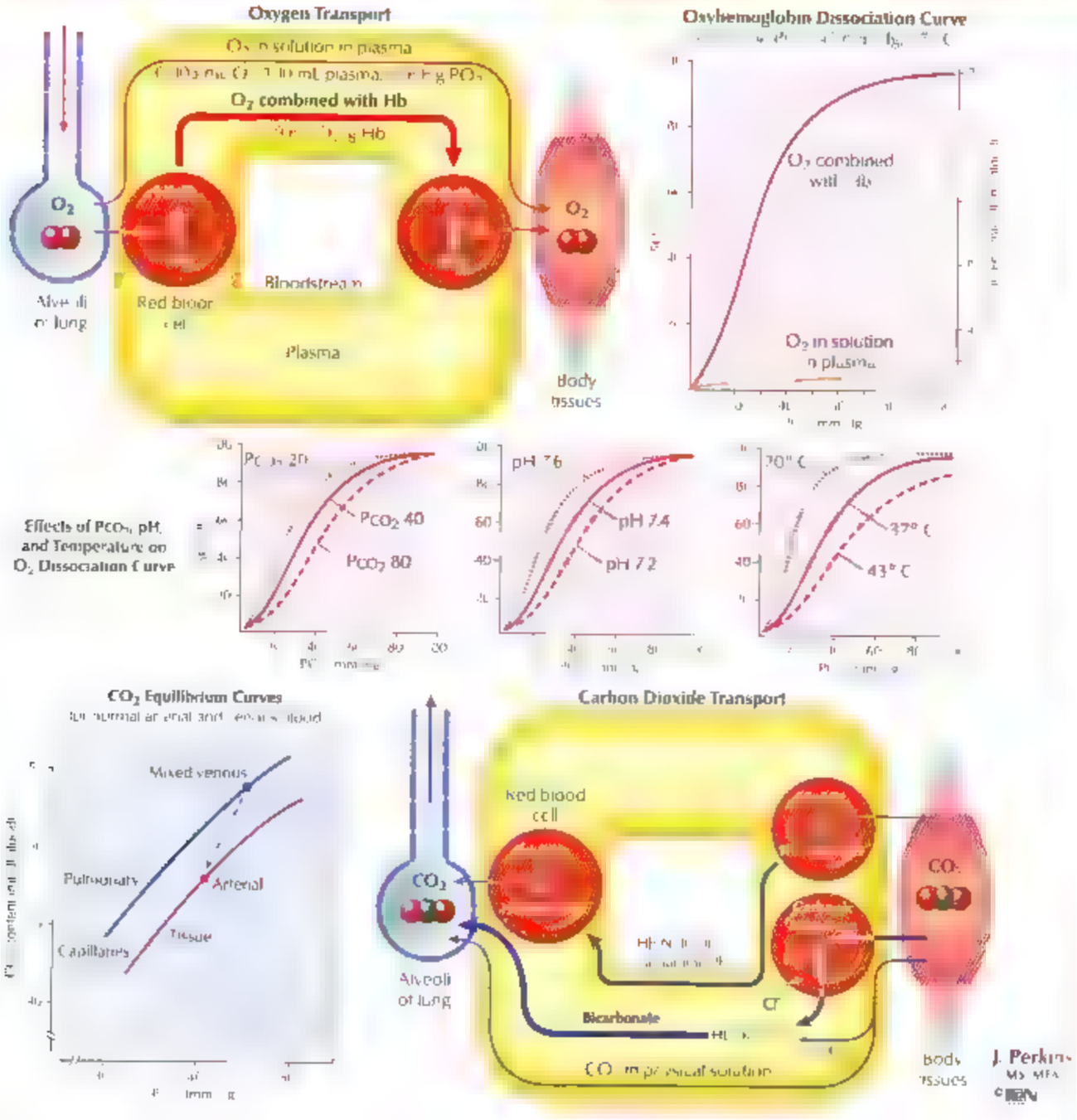
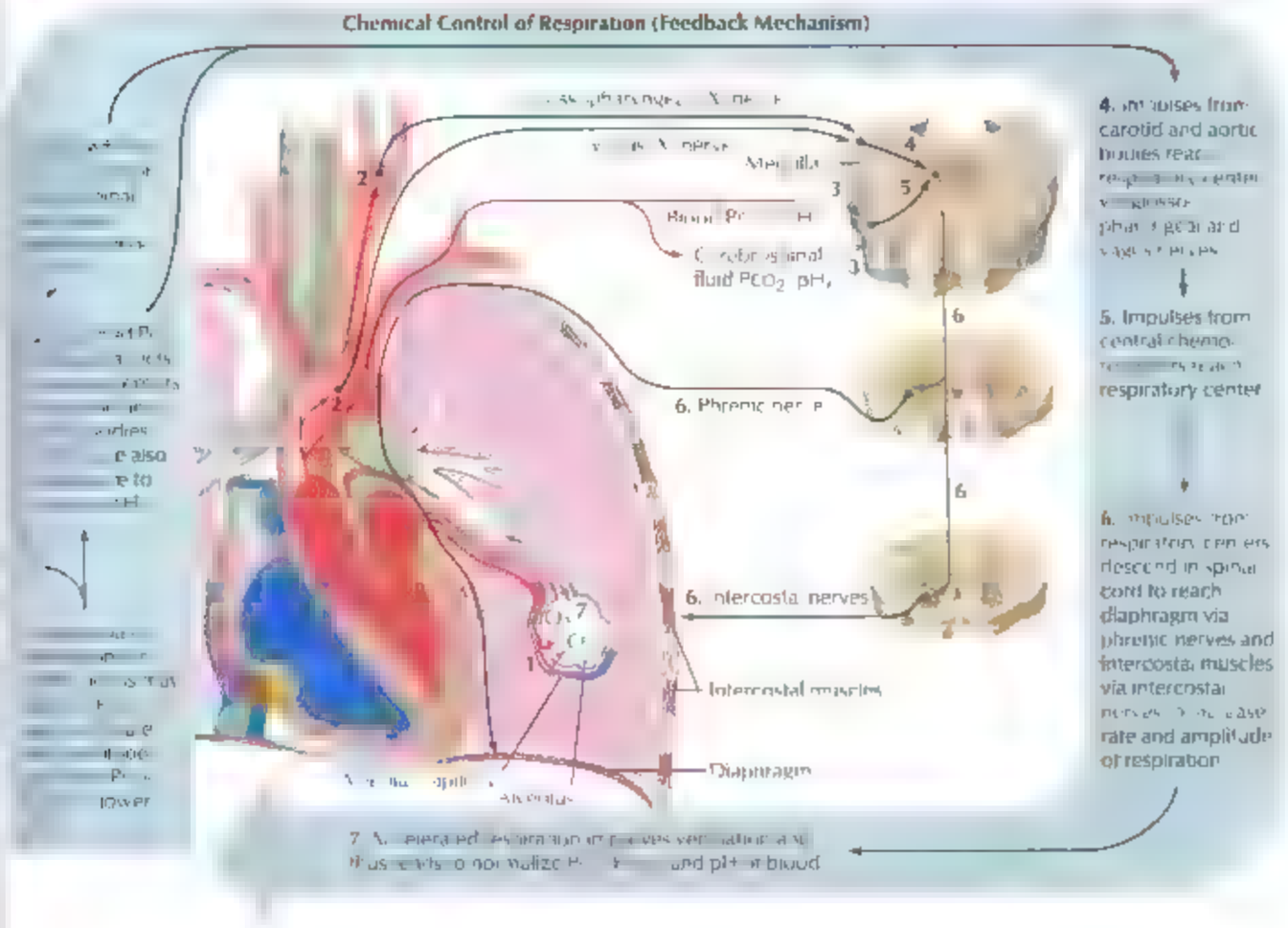


FIGURE 5.21 O_2/CO_2 EXCHANGE

During each breath, O_2 and CO_2 are exchanged across the alveolar-pulmonary capillary membrane (see Figure 5.19). Almost all of the O_2 carried to the tissues is bound to hemoglobin (Hb); only a small amount is dissolved and transported in plasma. As shown in the oxyhemoglobin dissociation curve, the binding of O_2 to Hb is dependent on the partial pressure (P_{O_2}). The percent saturation of Hb at 100 mm Hg P_{O_2} is about 97.5%, when the P_{O_2} is 40 mm Hg, the Hb is about 75% saturated. In the three middle panels, the effects of P_{CO_2}, pH, and temperature on the oxyhemoglobin dissociation curve are shown. The binding of O_2 to Hb is decreased by increased P_{CO_2}, decreased pH (acidosis), or increased body temperature (fever). CO_2 from the tissues is transported in the blood in the form of HCO_3^-. A small amount is transported in the dissolved state and some is carried in the form of carbaminohemoglobin. The bottom left panel shows the CO_2 equilibrium dissociation curve, which is much steeper than that for O_2, which is why the P_{CO_2} difference between arterial and mixed venous blood is small (about 5 mm Hg). The Bohr effect and thereby offloading of O_2 to the tissues is increased by increased P_{CO_2}, hypercapnia, decreased pH (acidosis), or increased body temperature (fever). CO_2 from the tissues is transported in the blood in the form of HCO_3^-. A small amount is transported in the dissolved state and some is carried in the form of carbaminohemoglobin.



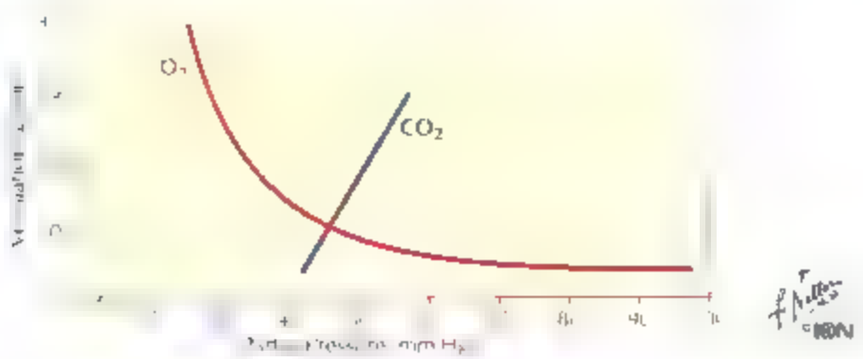


FIGURE 5.22 CONTROL OF RESPIRATION

[illegible] respiratory changes in arterial P_{CO_2} [illegible] opposite changes in the pH of the cerebrospinal fluid. The increased P_{CO_2} results in decreased cerebrospinal fluid pH, which increases respiratory rate and depth. Peripheral chemoreceptors in the carotid and aortic bodies sense changes in arterial P_{CO_2}, O_2, and pH and send signals via the glossopharyngeal and vagus nerves to the respiratory centers in the medulla. Increased respiratory rate and depth increase the rate of CO_2 removal from the blood and decrease arterial P_{CO_2} and H^+ concentration. Decreased respiratory rate and depth decrease the rate of CO_2 removal from the blood and increase arterial P_{CO_2} and H^+ concentration. Changes in arterial P_{CO_2} and pH are detected mainly by the central chemoreceptors, whereas changes in arterial P_{O_2} are detected mainly by the peripheral chemoreceptors.

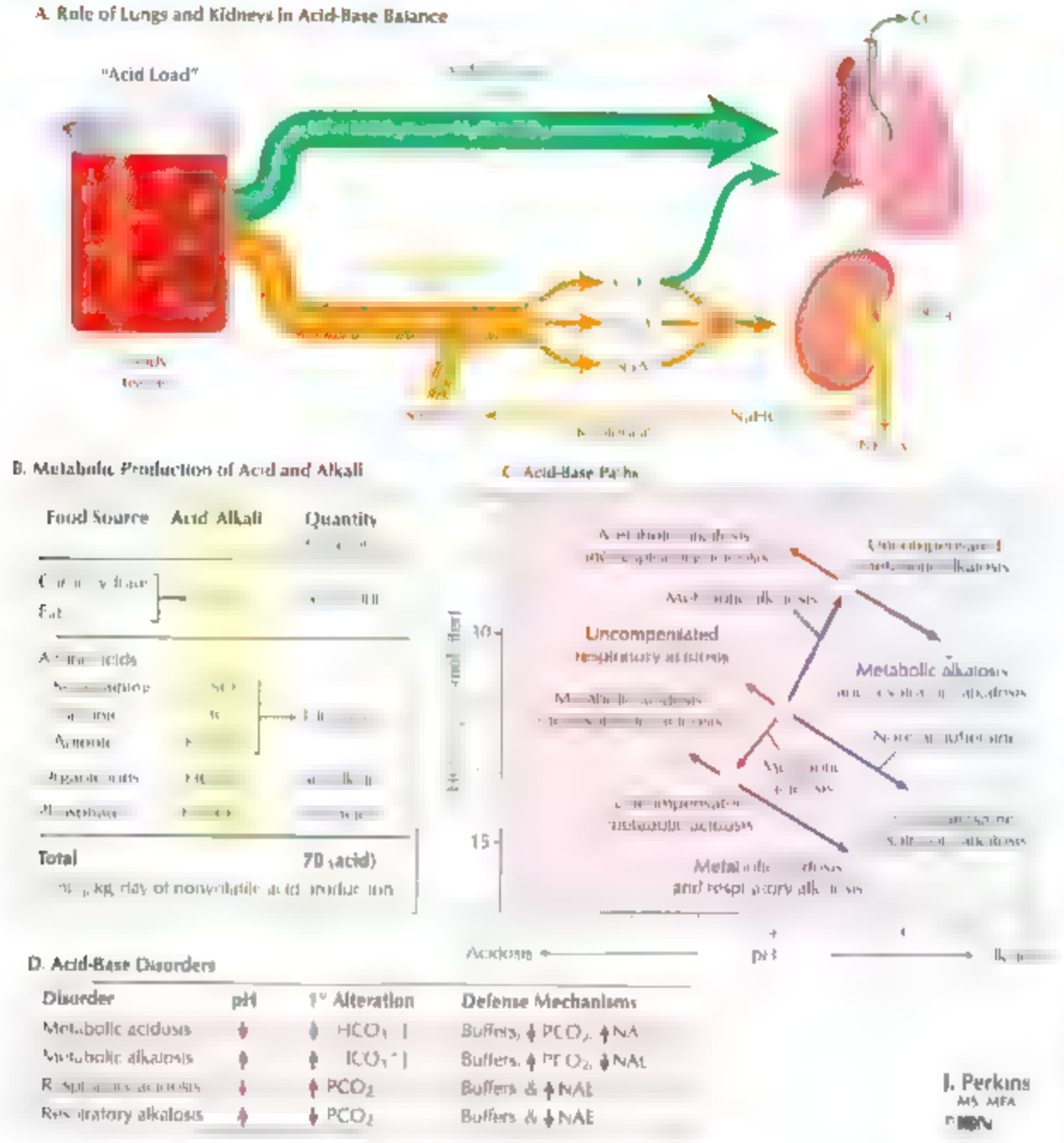


FIGURE 5.23 ACID-BASE BALANCE

A. Both the lungs and kidneys participate in acid-base balance. B. Our diet and cellular metabolism add acid and alkali to our system. [illegible] body fluid [illegible] ated by carbohydrate and fat metabolism, is efficiently eliminated by the lungs and does not normally affect acid-base balance. However, failure to excrete the CO_2 can alter acid-base balance. Nonvolatile acid (e.g. lactic acid) is buffered by HCO_3^- in the extracellular fluid. The kidneys must excrete this nonvolatile acid to replace the HCO_3^- used to neutralize these acids. The kidneys do this by [illegible] which also results in the addition HCO_3^- to the extracellular fluid (see Figure 5.20). The lungs [illegible] respond quickly and remove large quantities of volatile acid (hyperventilation). The kidneys take hours or days [illegible] resulting from alterations in the P_{CO_2} (respiratory disorders) and changes in the HCO_3^- (metabolic disorders). When a [illegible] disturbance occurs, intracellular (primarily proteins) and extracellular (primarily HCO_3^-) buffers minimize the change in body fluid pH [illegible] the lungs can adjust the P_{CO_2} within seconds to minutes for disorders, and the kidneys can adjust net acid excretion [illegible] days for respiratory disorders. Net acid excretion (NAE) includes acid excreted with urinary buffers and as NH_4^+ less HCO_3^- [illegible]

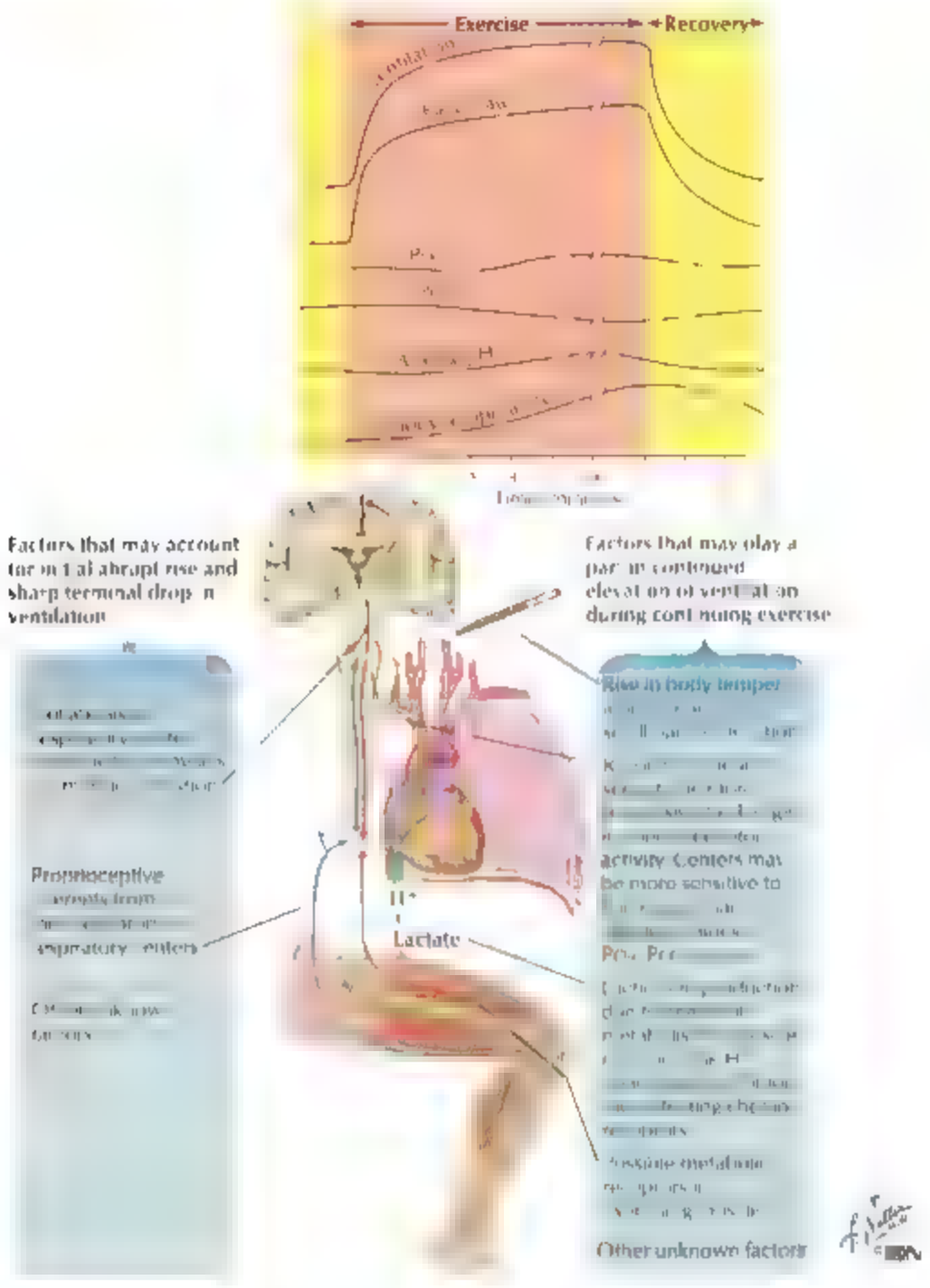
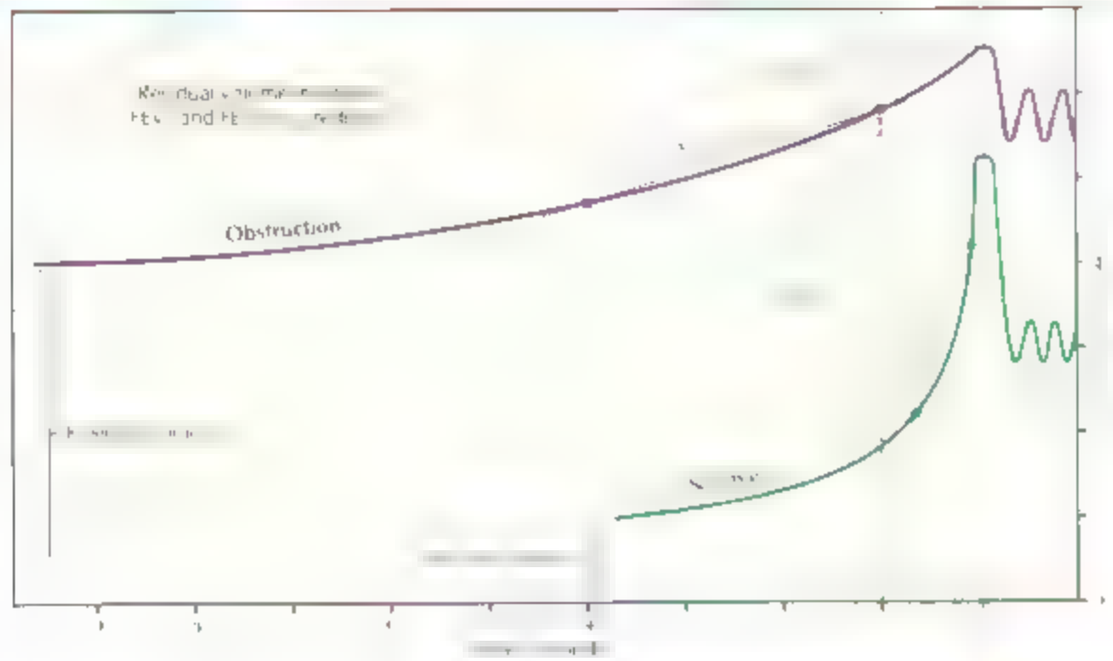
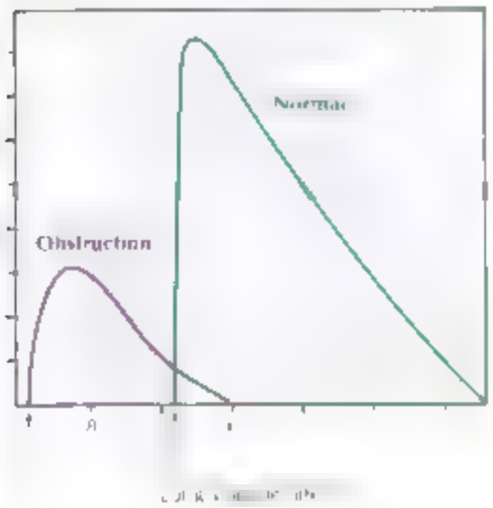


FIGURE 5.24 RESPIRATORY RESPONSE TO EXERCISE

Centriacinar
Centrilobular
Emphysema

FIGURE 5.25 OBSTRUCTIVE DISEASE: EMPHYSEMA





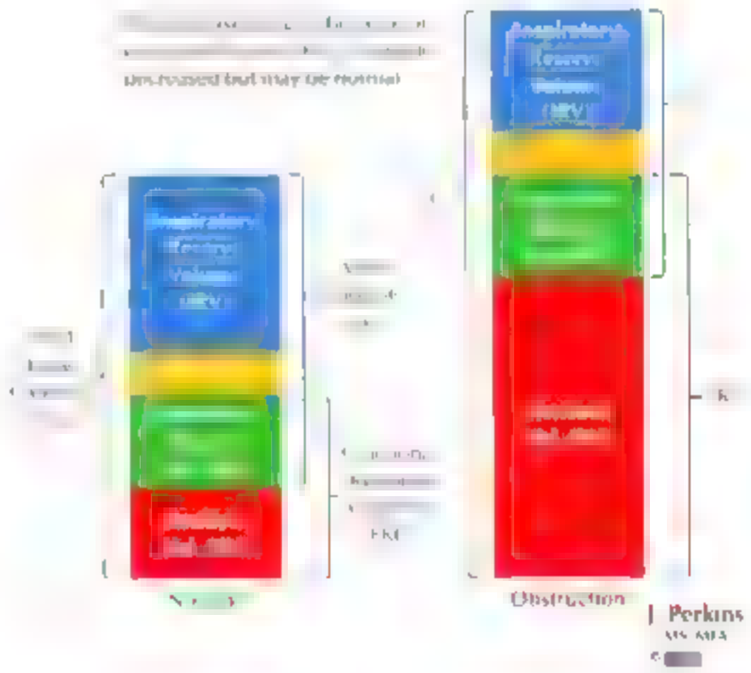
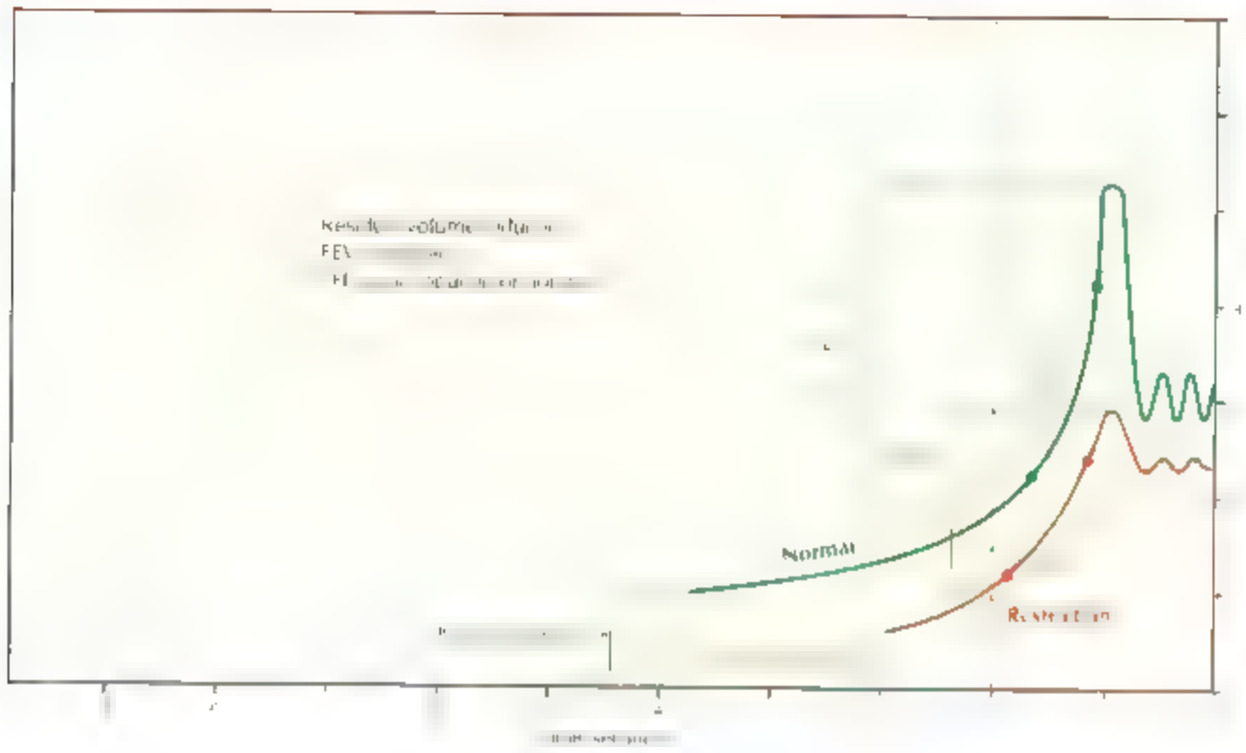


FIGURE 5.26 OBSTRUCTIVE LUNG DISEASE



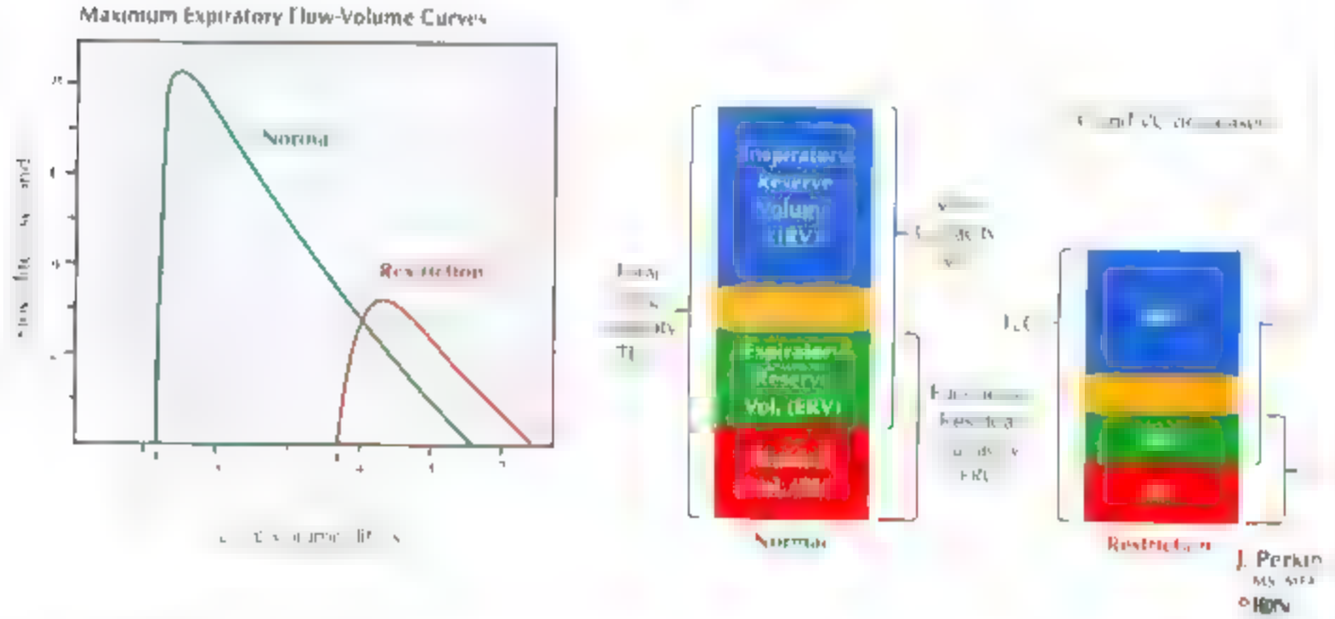


FIGURE 5.27 RESTRICTIVE PULMONARY DISEASE

Restrictive pulmonary disease refers to a group of disorders that [illegible] and VC (measured as [illegible] FVC. The [illegible] FEV [illegible] FVC, so the ratio of FEV [illegible] FVC [illegible] markedly decreased, this [illegible]

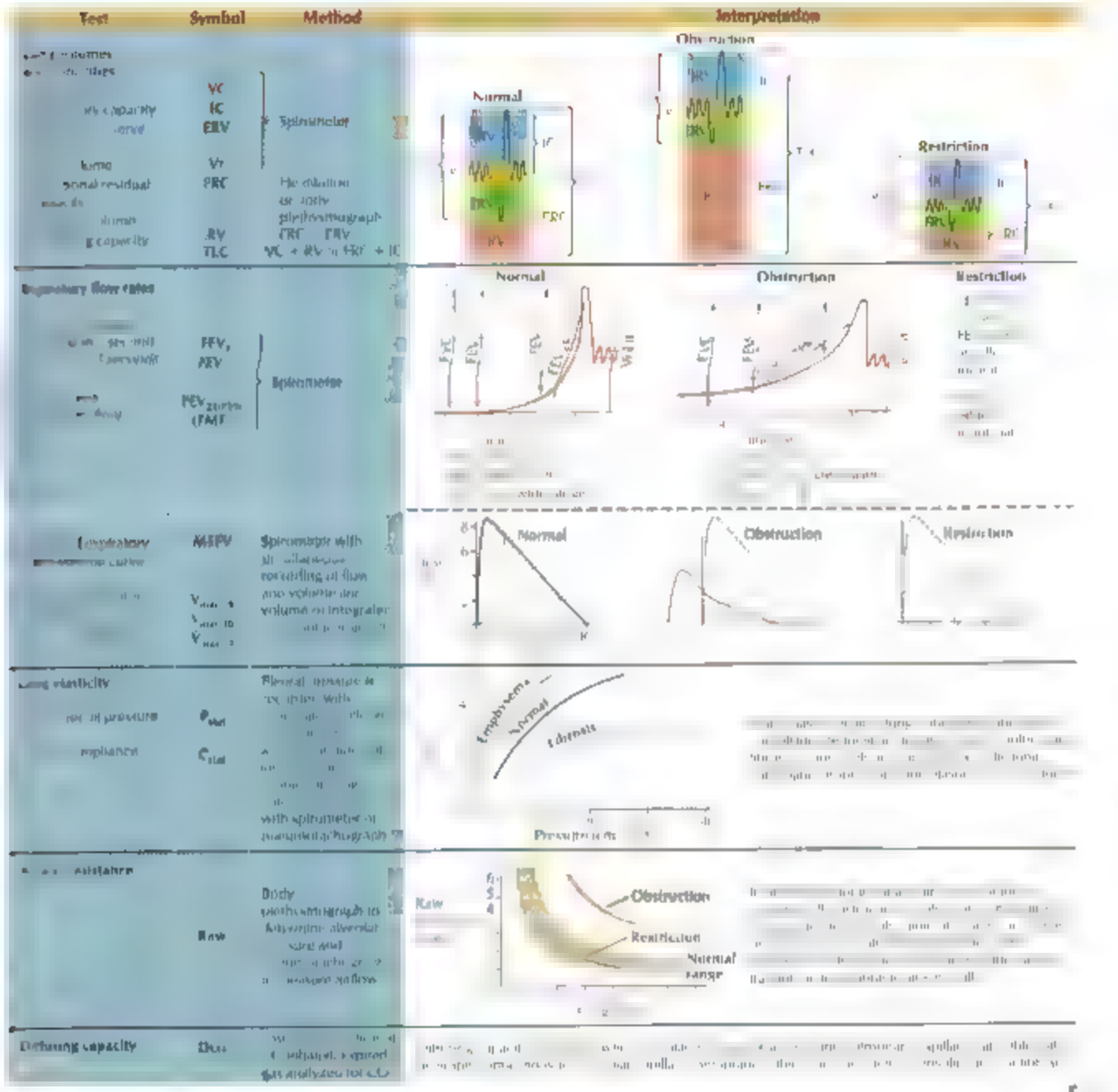


FIGURE 5.28 TESTS OF PULMONARY FUNCTION

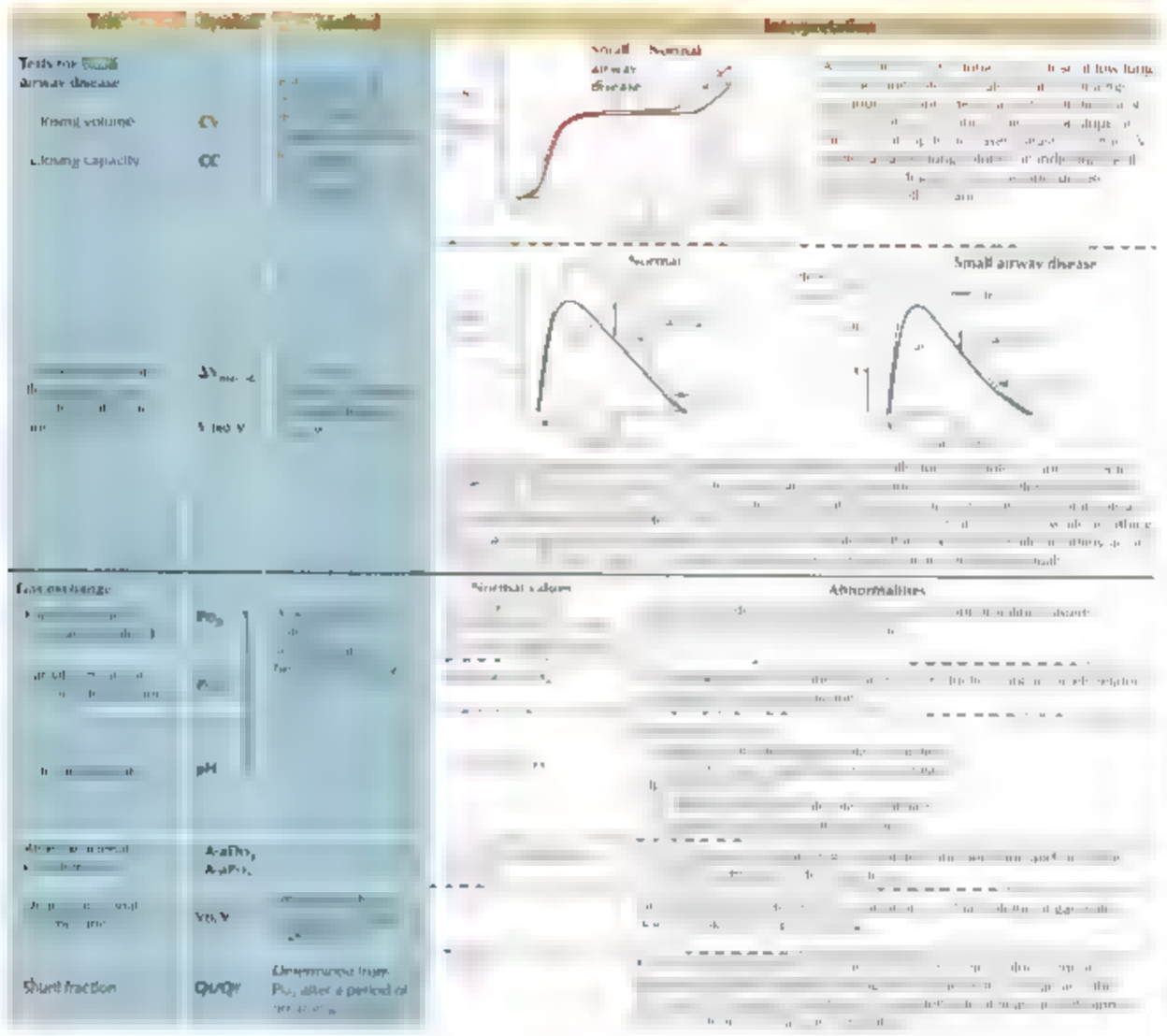


FIGURE 5.28 TESTS OF PULMONARY FUNCTION—CONT'D

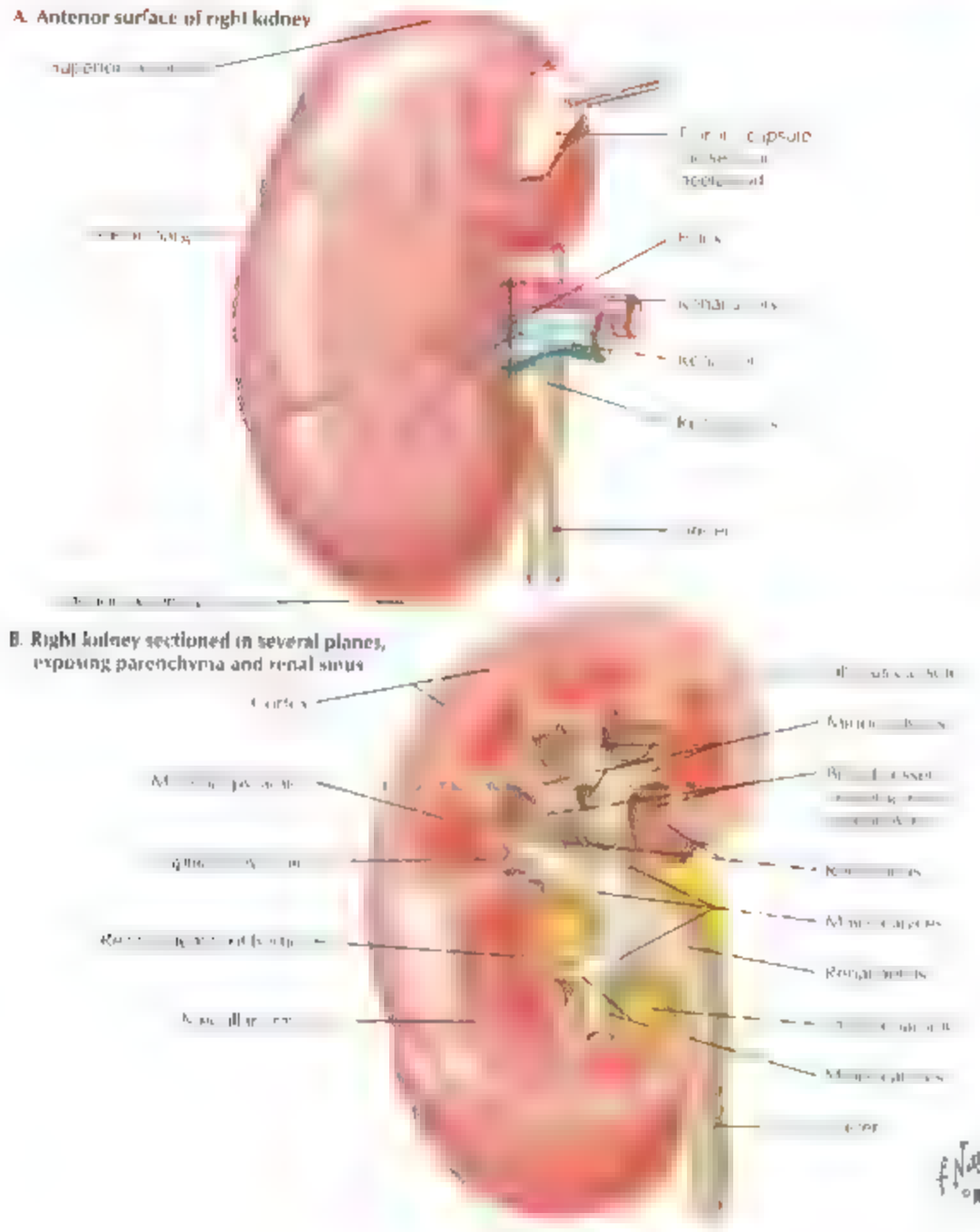


FIGURE 6.1 ANATOMY OF THE KIDNEY

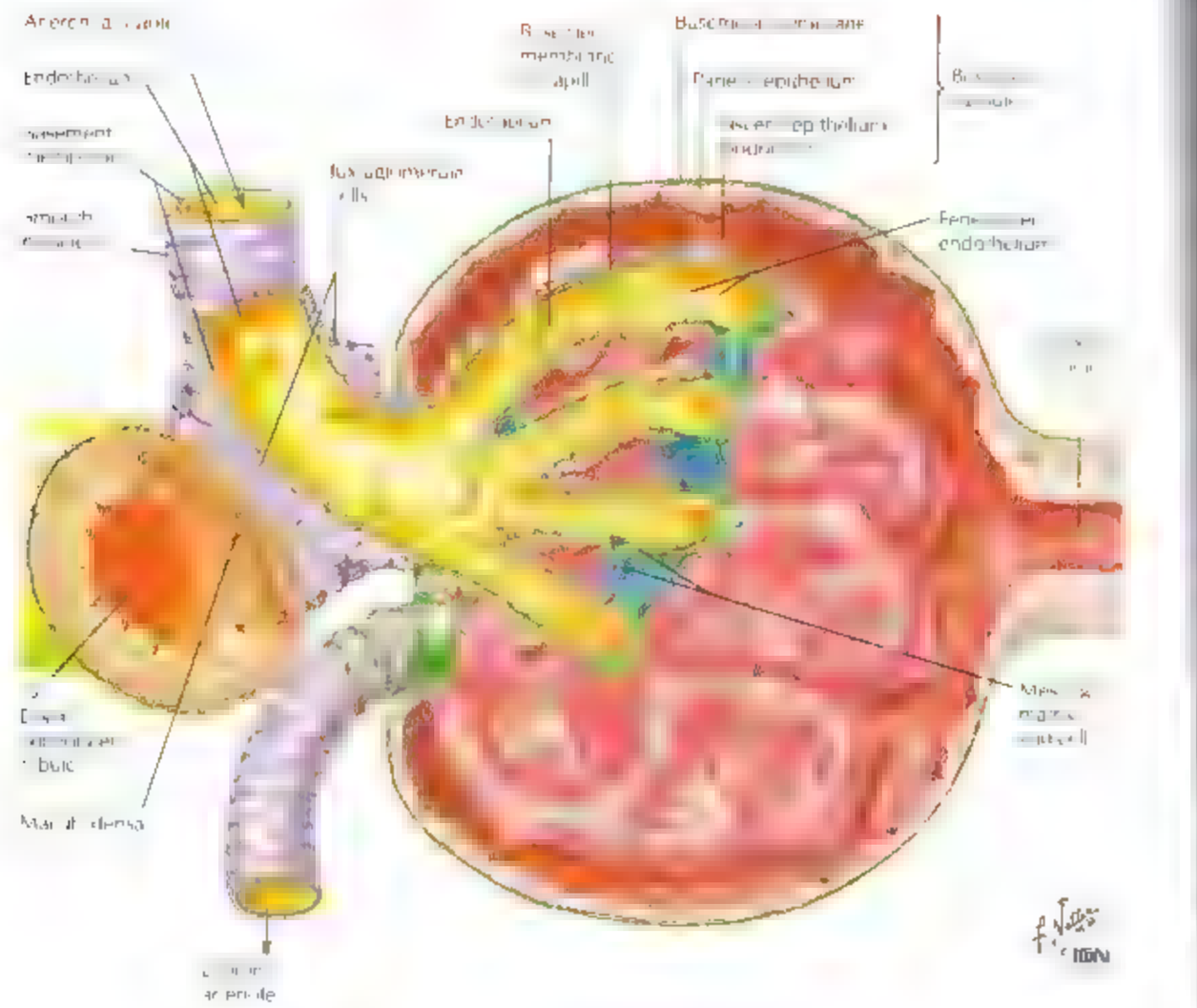


FIGURE 6.3 ANATOMY OF THE GLOMERULUS

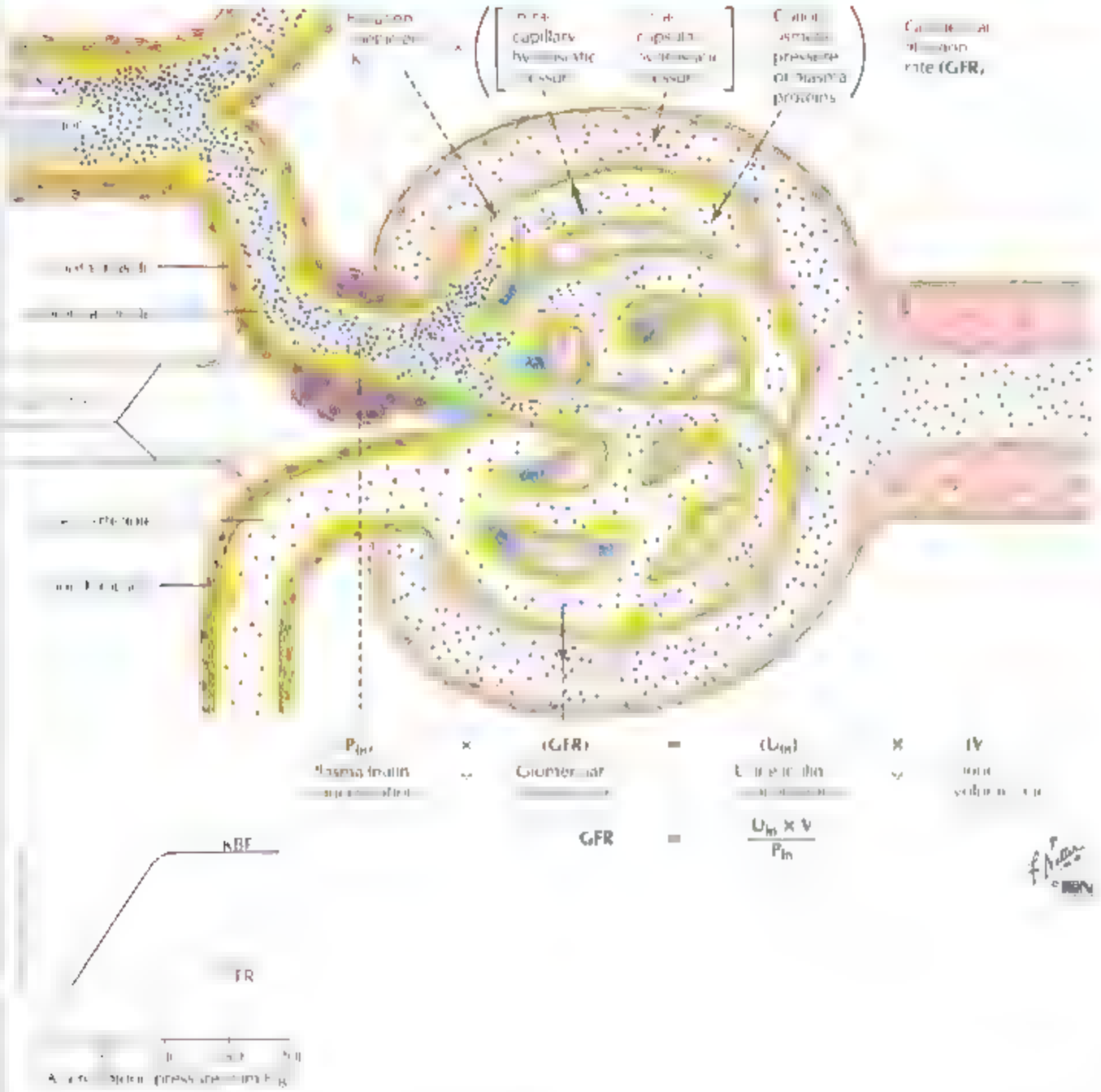


FIGURE 6.4 GLOMERULAR FILTRATION

[illegible] rate of plasma is produced at the glomerulus. It is devoid of [illegible] cells and proteins. Small [illegible] substances such as [illegible] concentrations similar to those of plasma. The glomerular [illegible] (GFR) is determined by the surface area and permeability of the glomerular capillaries and the [illegible] across the capillary wall. Hydrostatic pressure in the glomerular capillaries tends to push water and small solutes out of the blood, whereas hydrostatic pressure and capillary colloid osmotic pressure generated by the plasma proteins oppose filtration. GFR is relatively constant despite variations in blood pressure [illegible] Changes in glomerular hydrostatic pressure are responsible for physiologic regulation of the GFR. Alterations in vascular pathology processes such as diabetes and hypertension affect the glomerular capillaries, resulting in capillary hydrostatic pressure and [illegible] GFR. Although not shown, increased delivery of Na^+ to the [illegible] tubule [illegible] GFR via a feedback loop [illegible] number of mechanisms, as does the GFR. A group of peptides, [illegible] a high [illegible] concentrations, [illegible] the GFR. Atrial natriuretic peptide and [illegible] glandin E [illegible] afferent arteriole and increase the GFR [illegible] vasodilation.

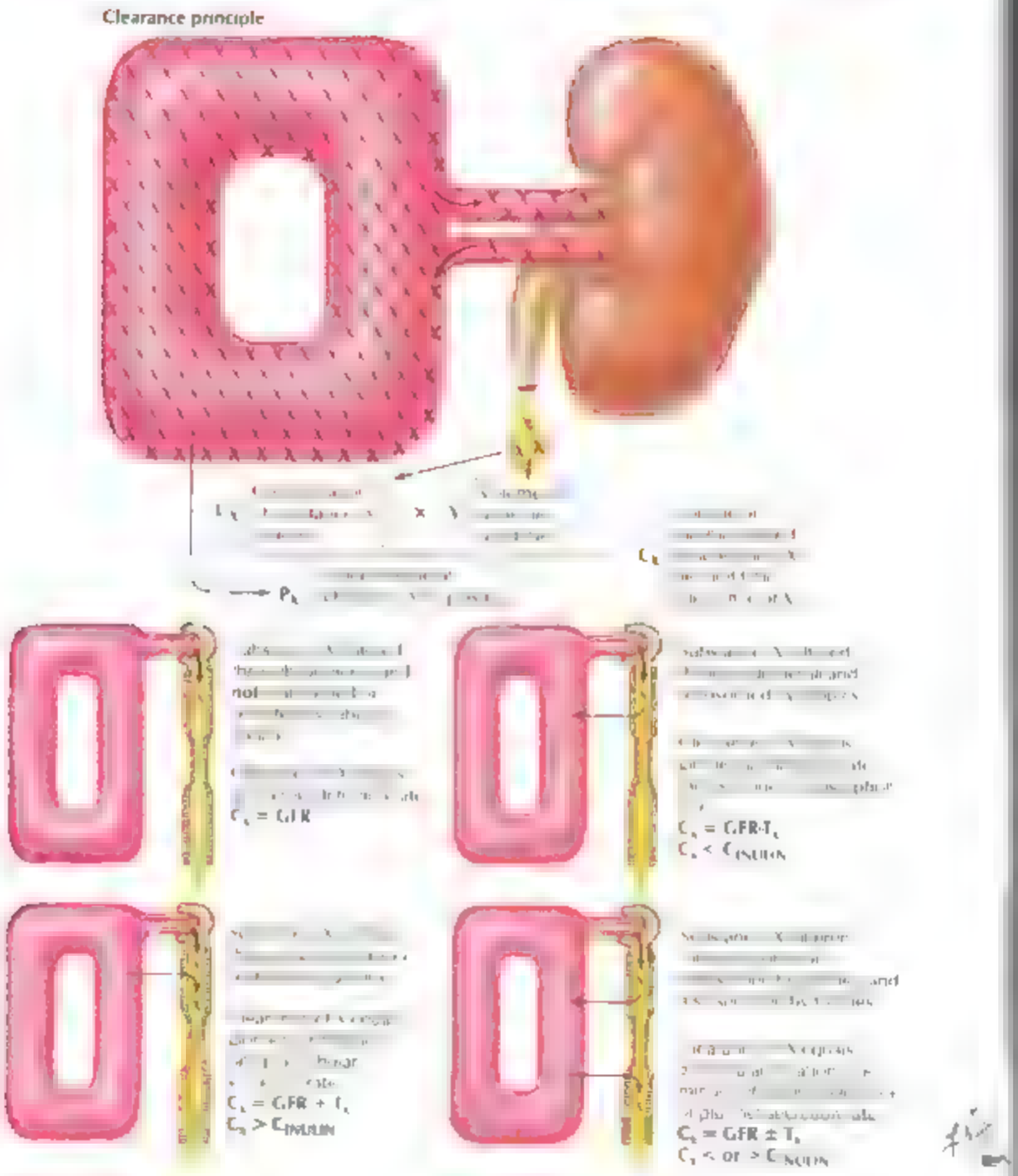


FIGURE 6.5 RENAL CLEARANCE

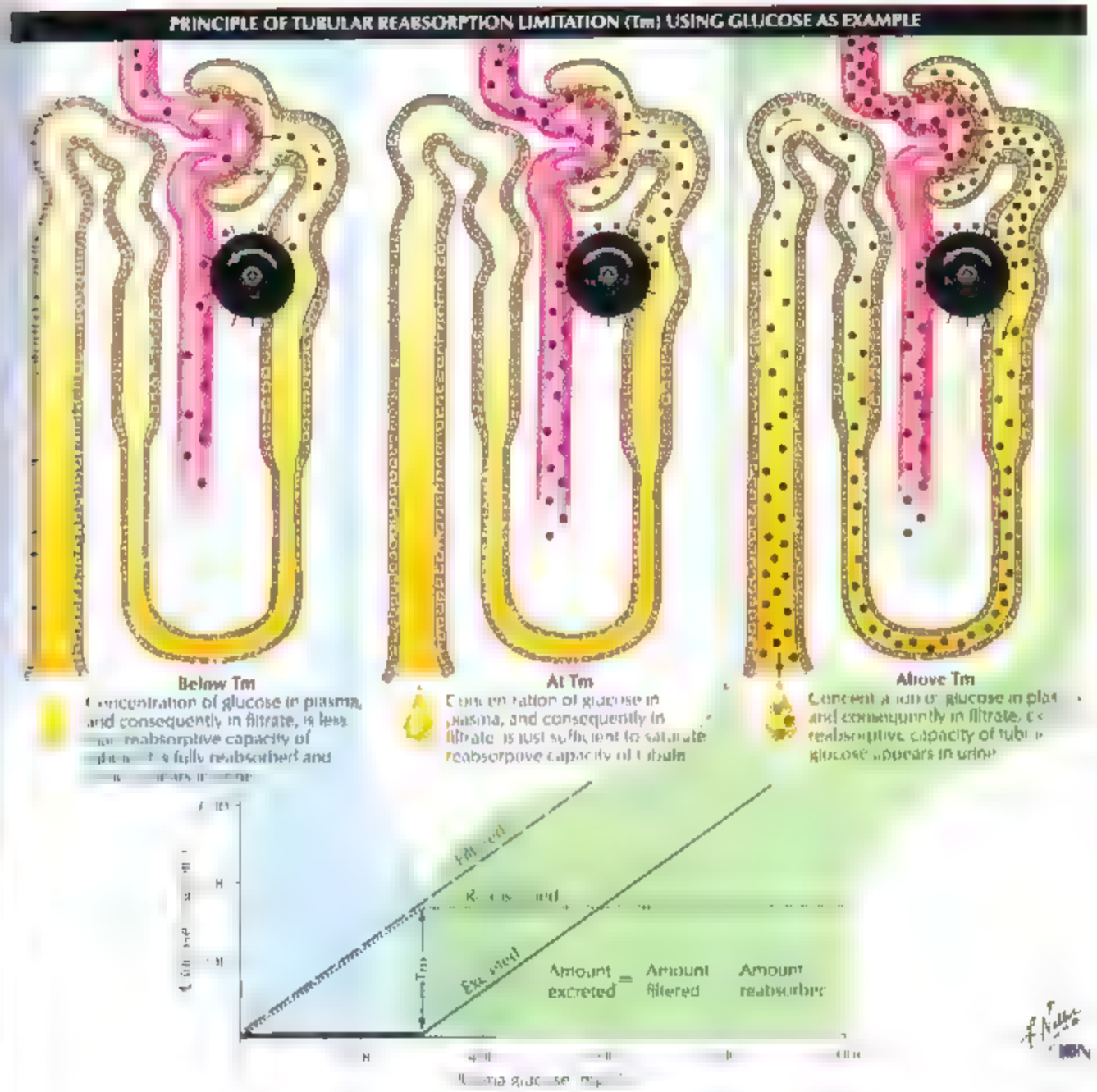


FIGURE 6.6 RENAL HANDLING OF GLUCOSE

[illegible] filtered at the glomerulus and reabsorbed by the proximal [illegible]. Normally no glucose appears in the urine because all of the [illegible] is reabsorbed [illegible] As the plasma concentration of glucose increases [illegible] to the point at which [illegible] glucose appears in the urine. Therefore, the renal clearance of glucose will increase as the plasma concentration of glucose increases

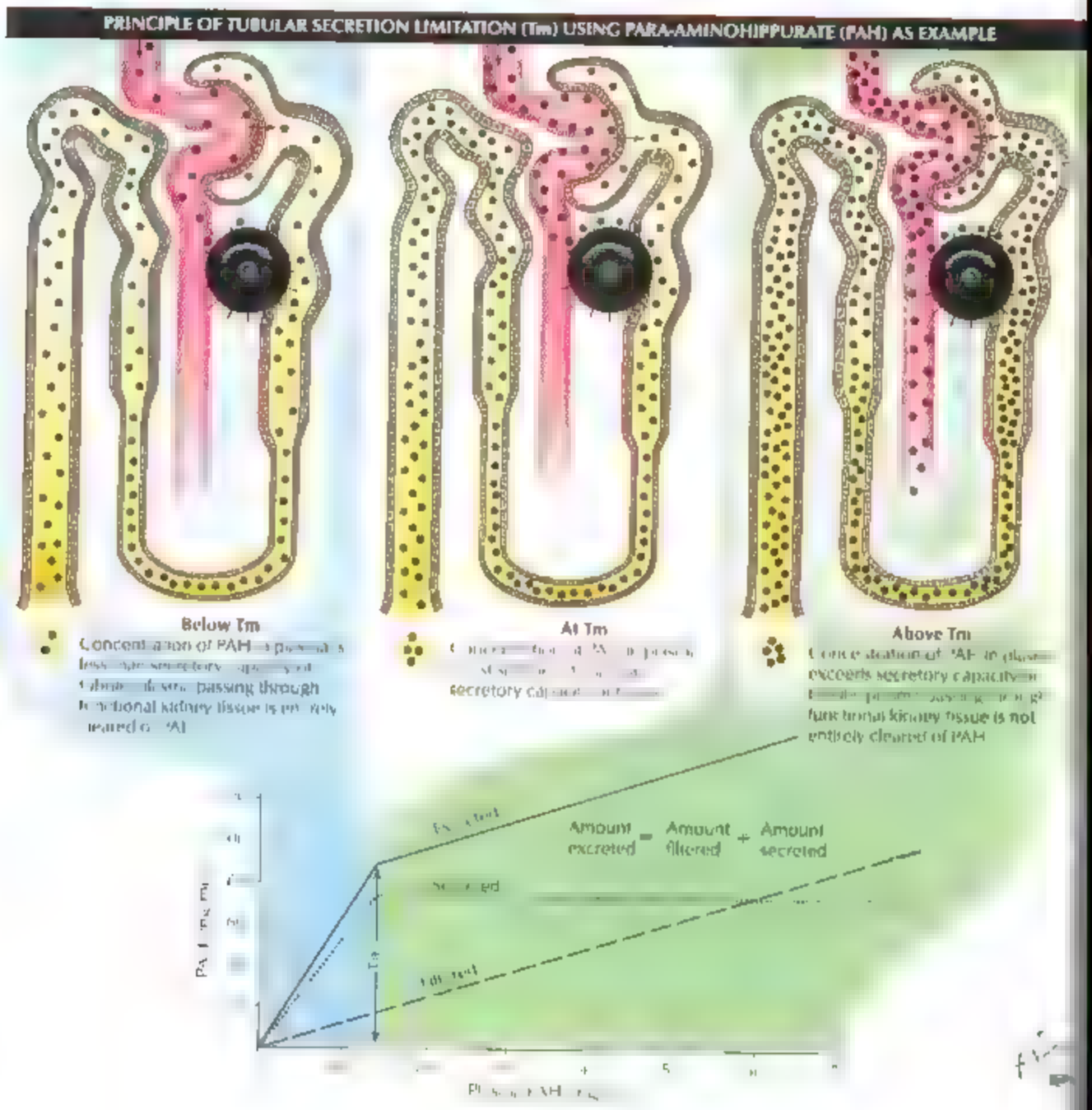


FIGURE 6.7 RENAL HANDLING OF *PARA*-AMINO HIPPURATE (PAH)

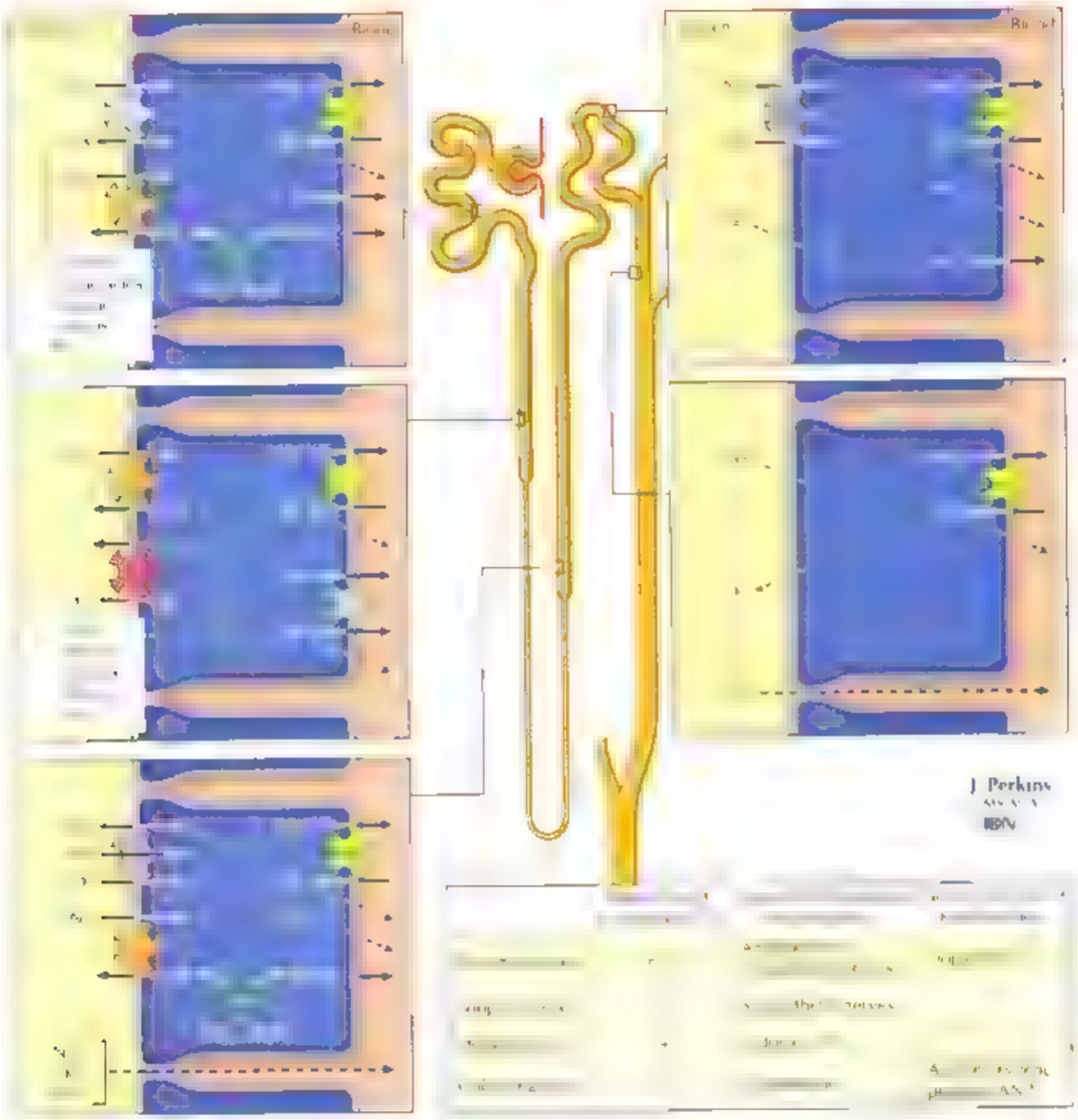


FIGURE 6.8 RENAL Na REABSORPTION

MECHANISM OF ANTIDIURETIC HORMONE IN REGULATING URINE VOLUME AND CONCENTRATION

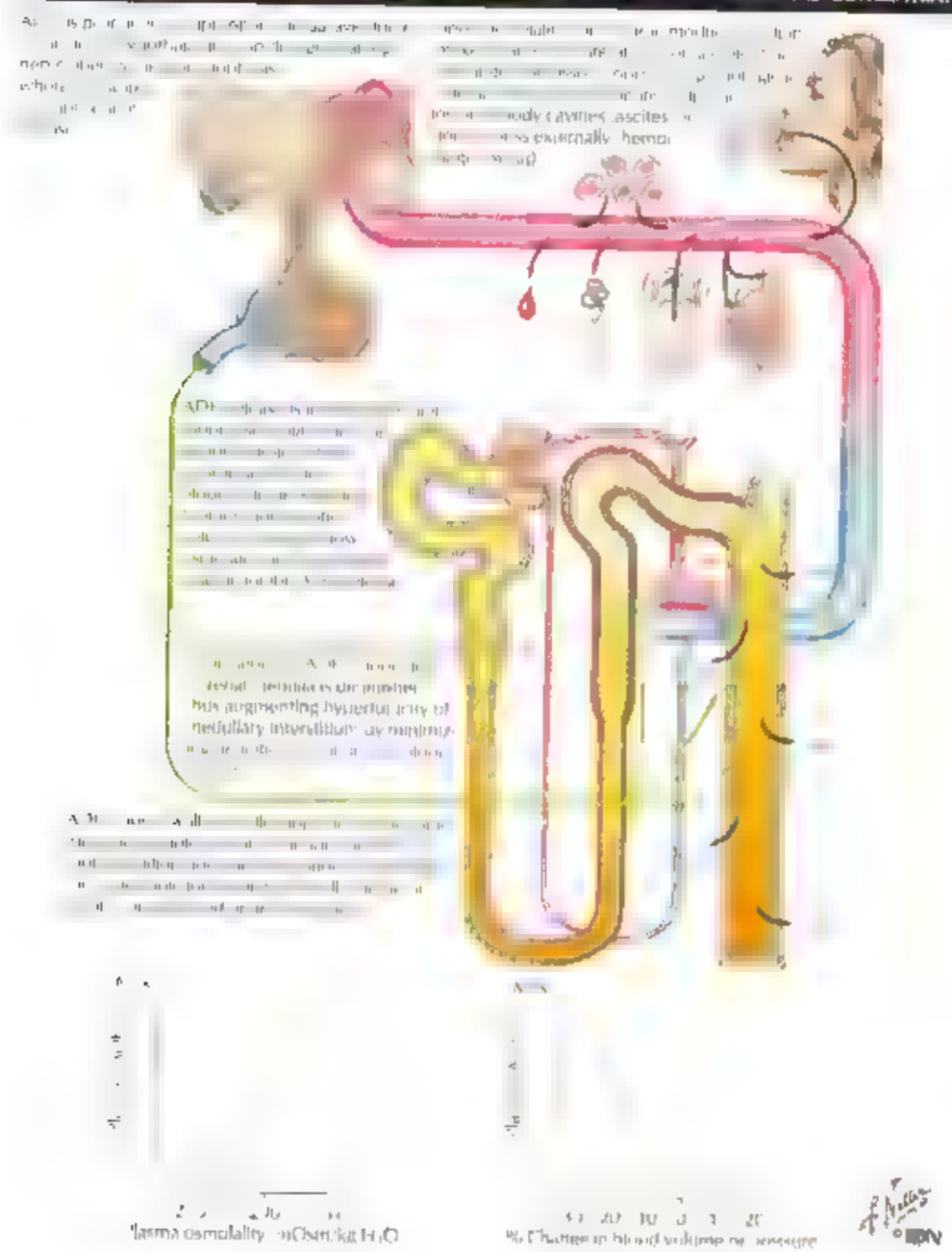


FIGURE 6.9 ADH SECRETION AND ACTION

ADH regulates the volume of water excreted by the kidneys. Its secretion is regulated by the osmolality of the body fluids and the [illegible] Decreases in blood volume and pressure of 10% to 15% or more are needed to effect ADH secretion. The blood volume and pressure sensors are found in the large pulmonary vessels, the carotid sinus [illegible]

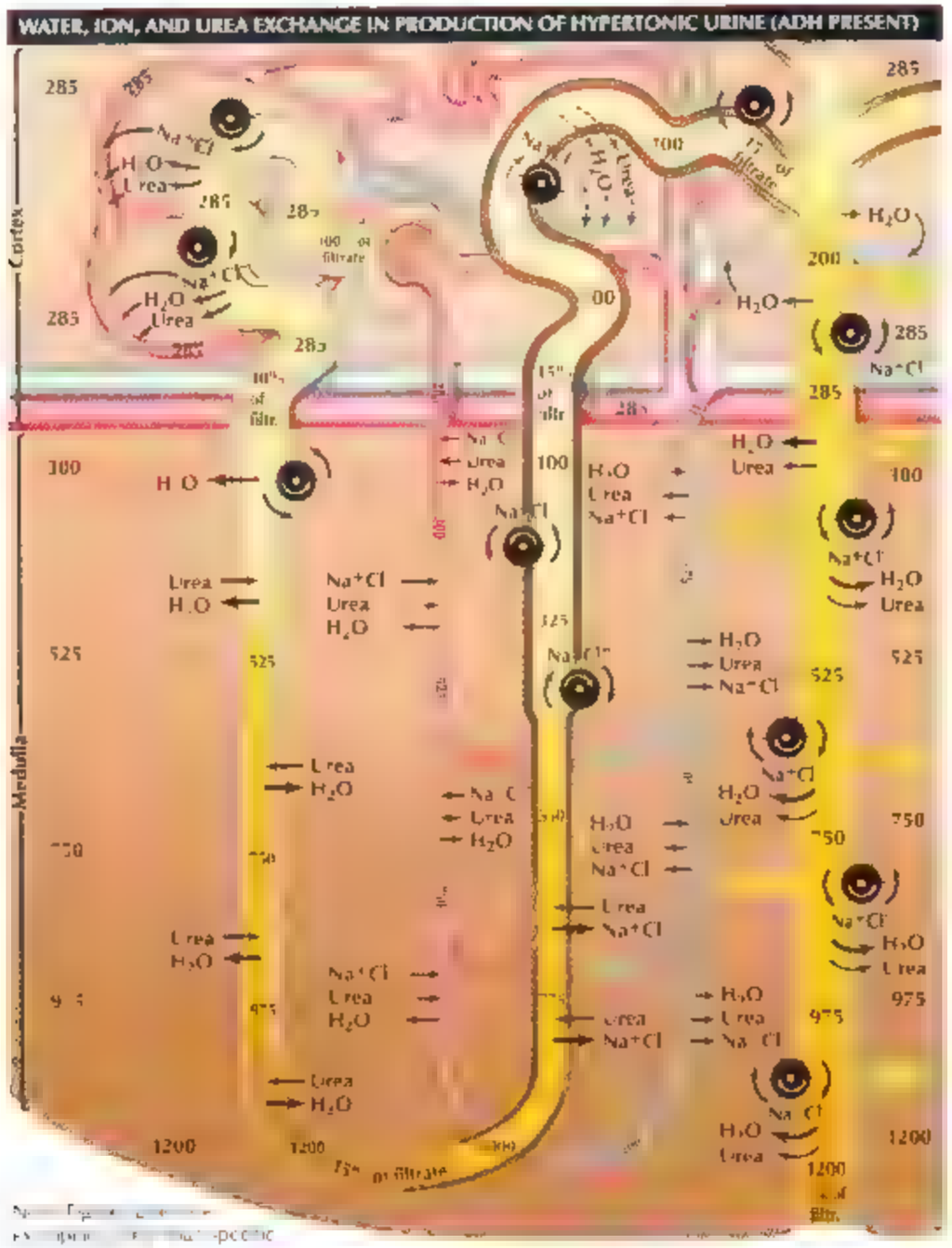


FIGURE 6.10 CONCENTRATION OF THE URINE

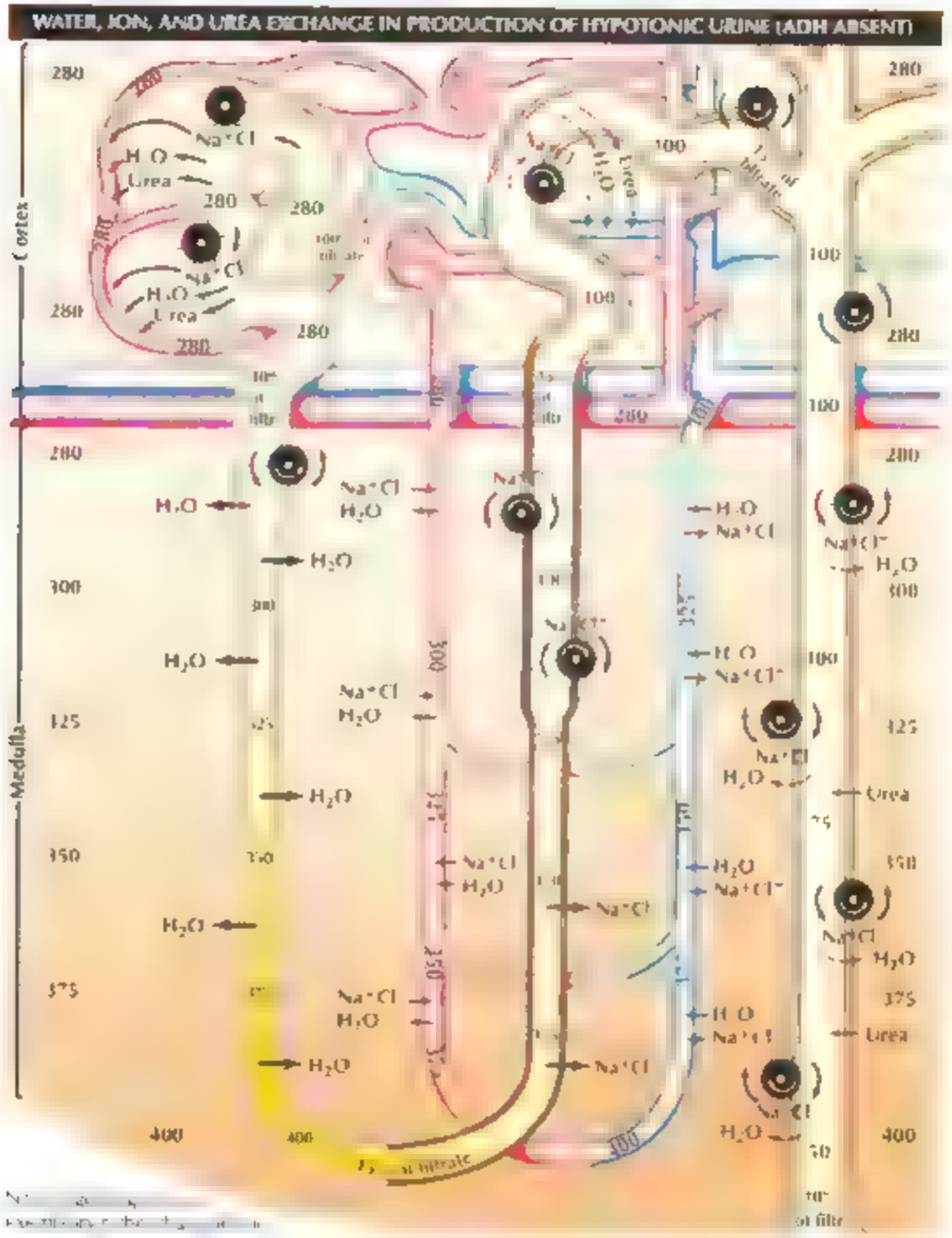


FIGURE 6.11 DILUTION OF THE URINE

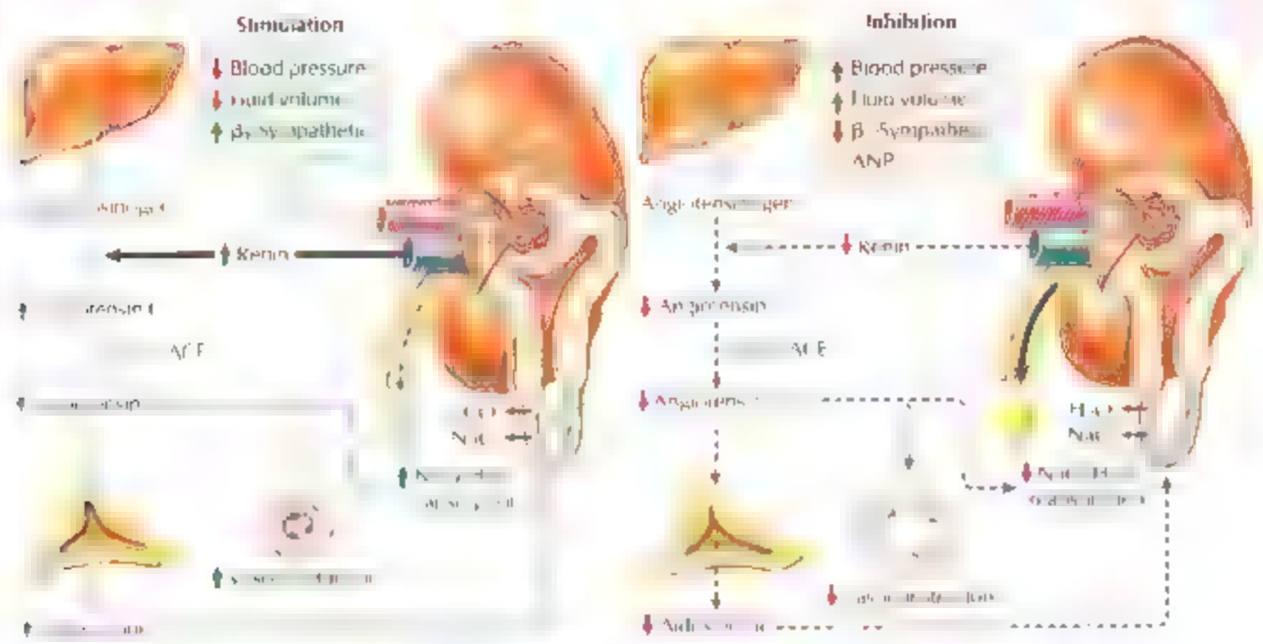


FIGURE 6.12 RENIN-ANGIOTENSIN-ALDOSTERONE SYSTEM

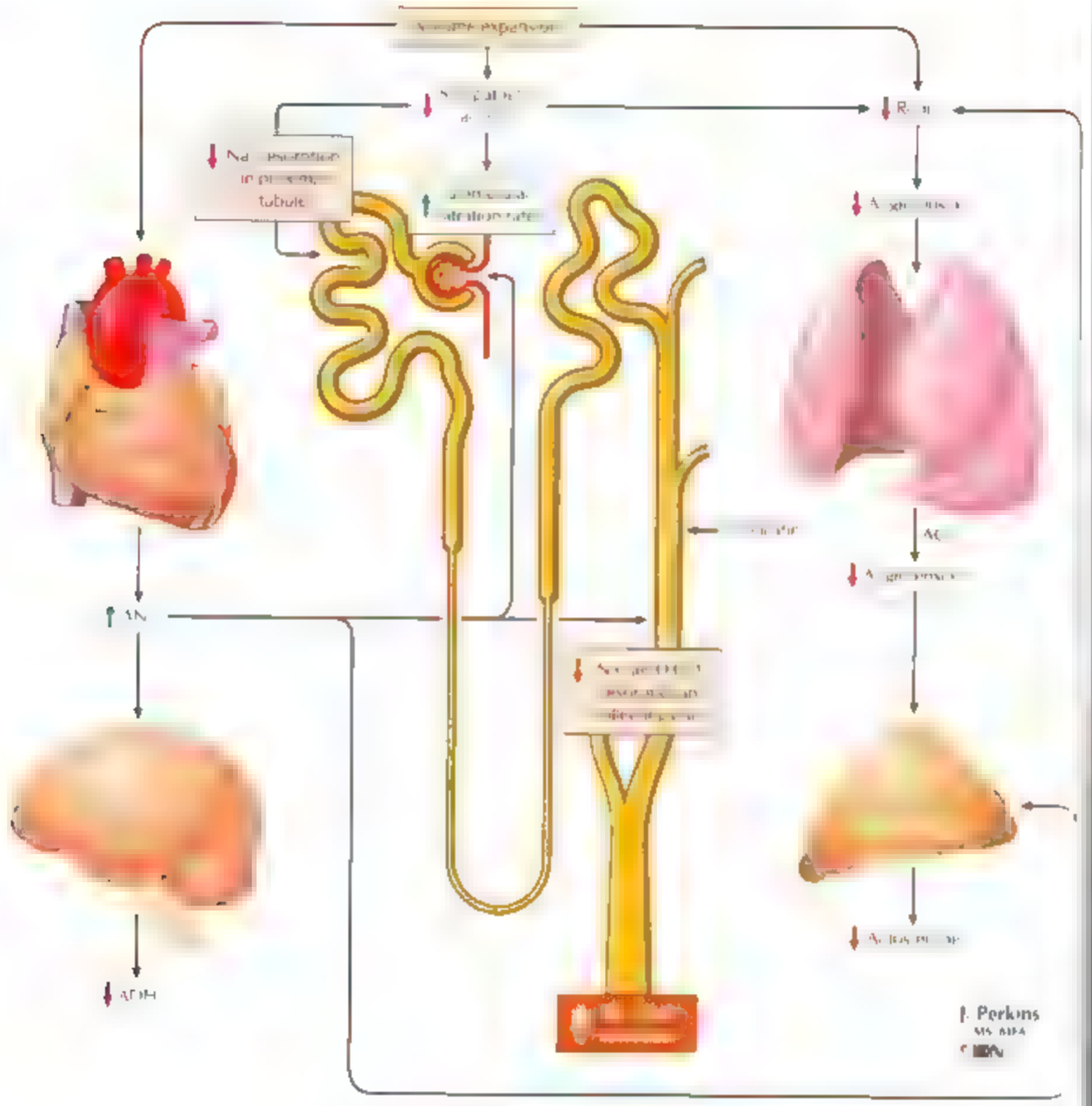


FIGURE 6.13 RESPONSE TO VOLUME EXPANSION

The kidneys respond to an increase in the volume of the extracellular fluid volume expansion by increasing the excretion of NaCl and water. The initial mechanisms in this response are the stretch-mediated release of atrial natriuretic peptide (ANP) and the inhibition of renin release by the juxtaglomerular apparatus. Because the sympathetic nervous system and angiotensin II also affect Na+ reabsorption by the proximal tubule, the ANP response is augmented by

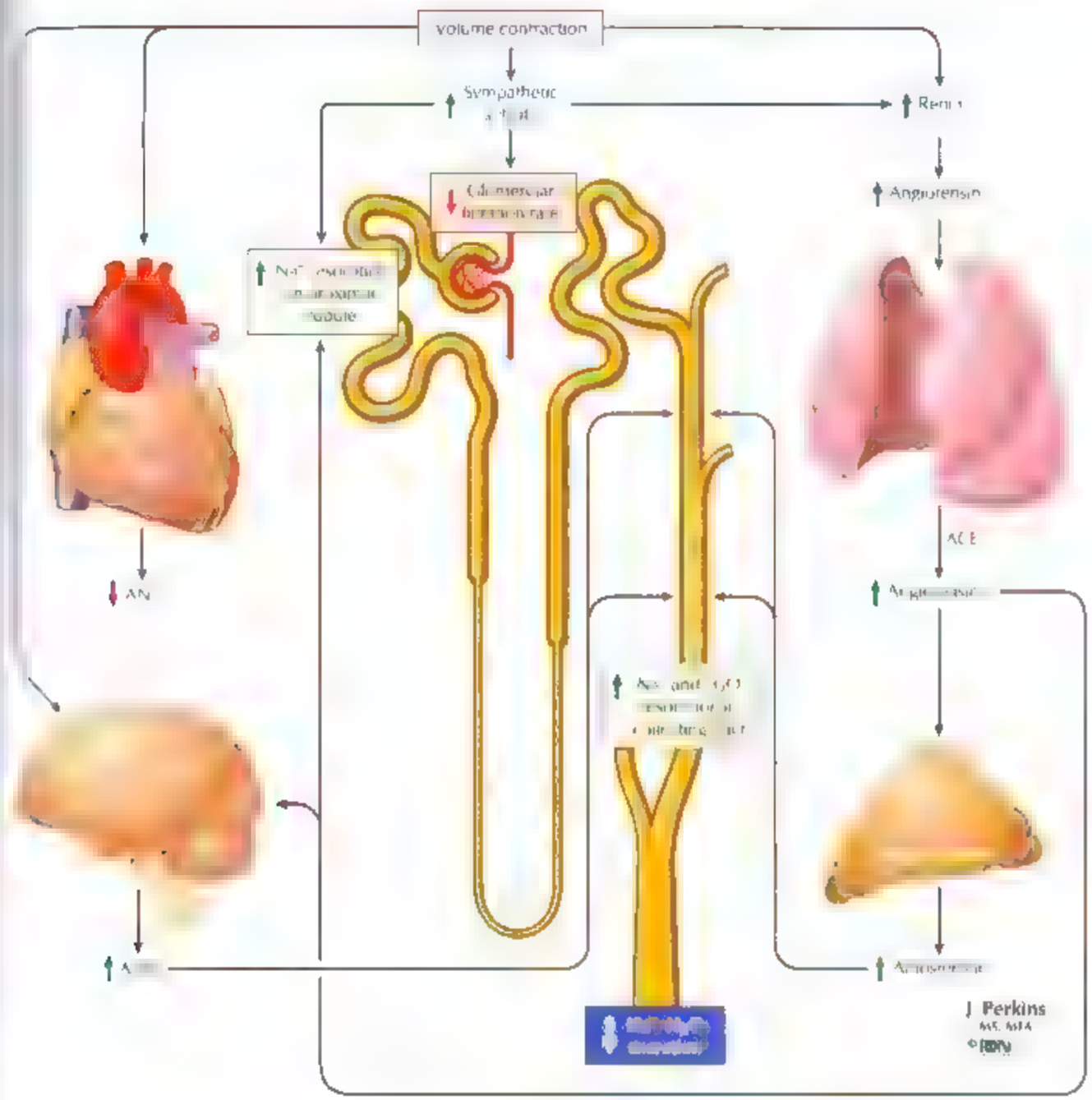
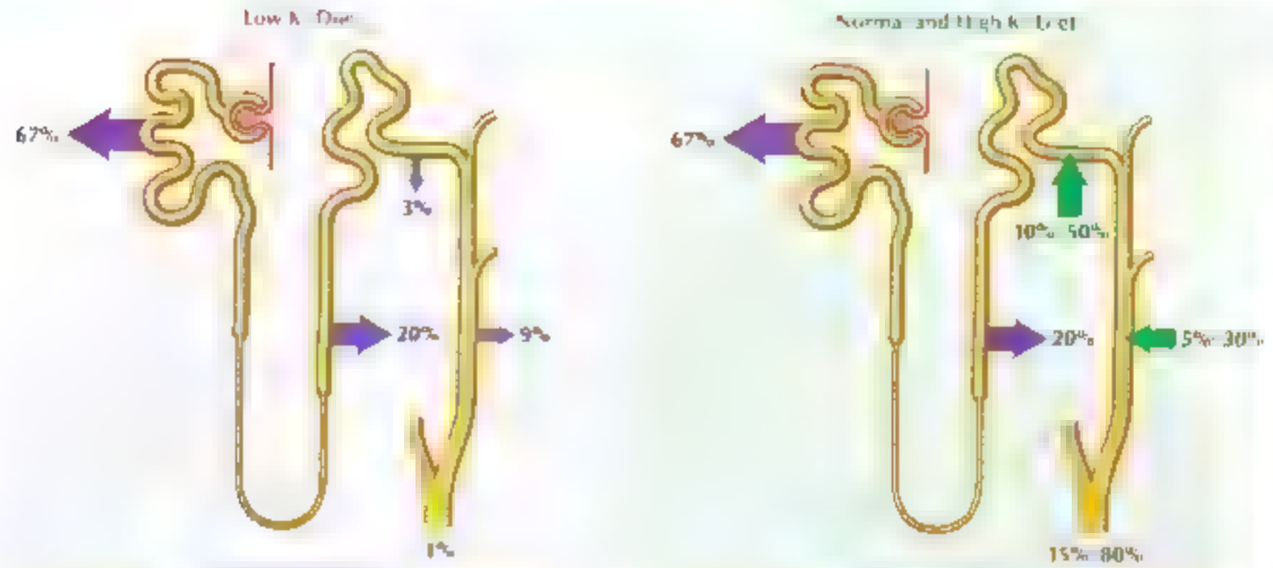


FIGURE 6.14 RESPONSE TO VOLUME CONTRACTION

[illegible] decrease. The adjustments that restore extracellular volume [illegible] by decreasing [illegible] and [illegible]. The primary mechanisms in this response are summarized [illegible]. Net [illegible] results [illegible] decrease [illegible] and stimulation of [illegible] reabsorption along [illegible]. The [illegible] sympathetic and renin-angiotensin-aldosterone systems are activated, [illegible] natriuretic peptide (ANP) secretion is suppressed. The sympathetic and renin-angiotensin-aldosterone systems [illegible] decrease the GFR and [illegible] tubular [illegible] and [illegible] reabsorption. Natriuresis [illegible] levels [illegible] ANP [illegible] decrease [illegible] reabsorption. ADH, [illegible]. Abbreviation: ACE, [illegible] converting enzyme.



Physiologic Factors That Stimulate K Secretion	Physiologic Factors That Stimulate K Reabsorption	Factors That Alter K Secretion Secondarily	Factors That Alter K Secretion Indirectly
Aldosterone Hyperkalemia	Low K diet	Increased tubular flow rate Acute and chronic alkalosis Chronic acidosis	Acute acidosis

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FIGURE 6.15 POTASSIUM EXCRETION

The kidneys are the primary route for excretion of K from the body, and the amount excreted varies with dietary K intake. On a low K diet, only about 1% of the filtered load is excreted. With a normal or high K diet, varying amounts of K are excreted. Most of the K that is excreted under these conditions reflects K that is secreted into the tubular fluid by the collecting duct. The principal cell of the cortical collecting duct secretes K in response to elevated K concentration and tubular flow rate. The mechanisms for K reabsorption by the proximal tubule, thick ascending limb of Henle loop, and intercalated cell of the collecting duct are depicted in Figure 6.16. These are not influenced by dietary K

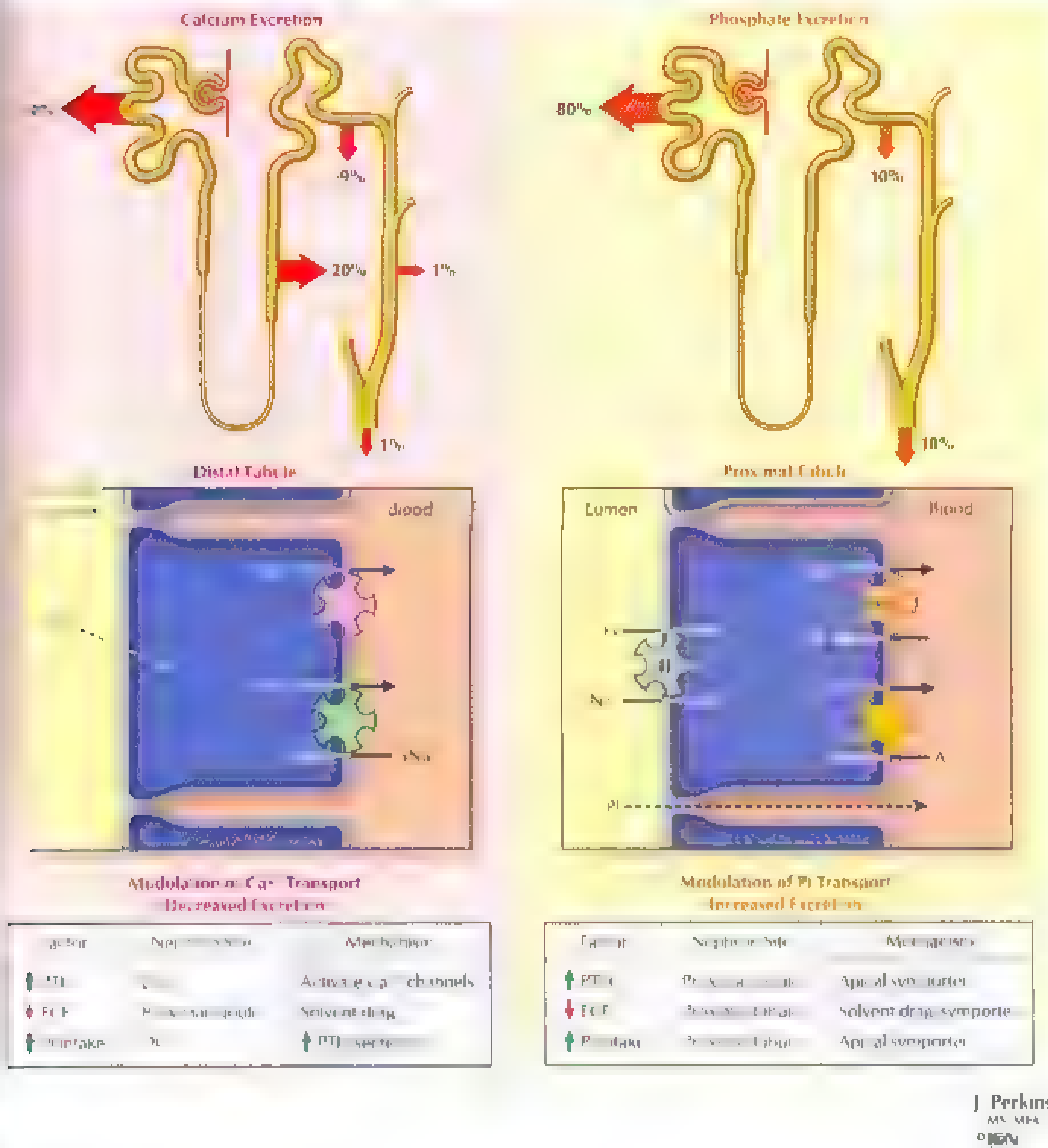
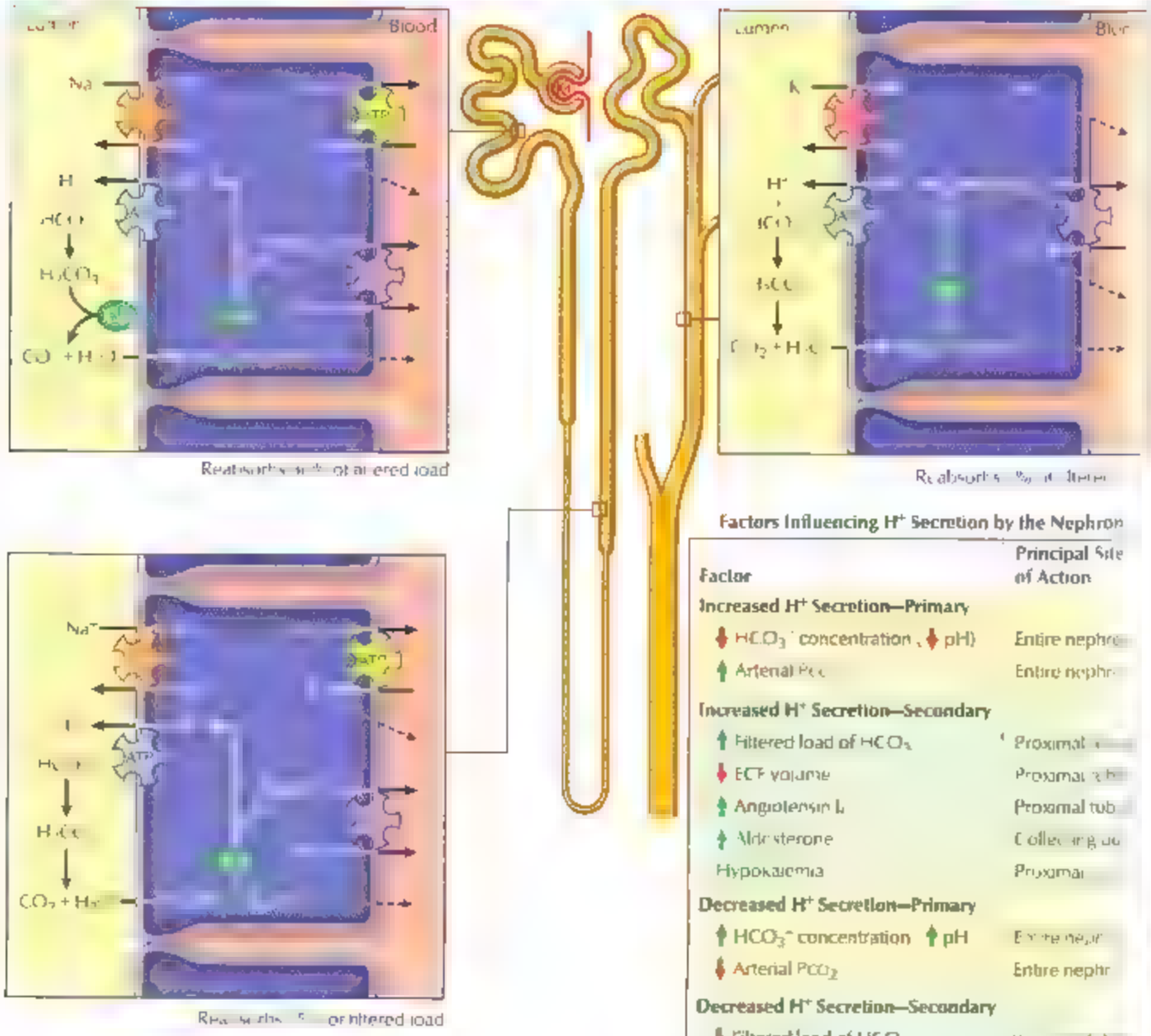


Figure 6.16 Calcium and Phosphate Excretion

[illegible] absorption along the entire nephron [illegible] parathyroid hormone (PTH) [illegible] calcium reabsorption [illegible] changes in the extracellular fluid [illegible] excretion. However, [illegible] Na⁺ reabsorption by the proximal tubule in response [illegible] ECF [illegible] Phosphate is primarily reabsorbed by the proximal tubule [illegible] which acts on the proximal tubule [illegible]. Changes in the ECF [illegible] Like Ca²⁺, [illegible] changes in Na⁺ [illegible] maintaining phosphate balance.



Factors Influencing H^+ Secretion by the Nephron

Factor	Principal Site of Action
Increased H^+ Secretion—Primary	
↓ HCO_3^- concentration (↓ pH)	Entire nephron
↑ Arterial P_{CO_2}	Entire nephron
Increased H^+ Secretion—Secondary	
↑ Filtered load of HCO_3^-	Proximal tubule
↓ ECF volume	Proximal tubule
↑ Angiotensin II	Proximal tubule
↑ Aldosterone	Collecting duct
Hypokalemia	Proximal tubule
Decreased H^+ Secretion—Primary	
↑ HCO_3^- concentration ↑ pH	Entire nephron
↓ Arterial P_{CO_2}	Entire nephron
Decreased H^+ Secretion—Secondary	
↓ Filtered load of HCO_3^-	Proximal tubule
↑ ECF volume	Proximal tubule
↓ Aldosterone	Collecting duct
Hyperkalemia	Proximal tubule

Figure 6.17 HCO_3^- Reabsorption

Bicarbonate is freely filtered and reabsorbed by the process of H^+ secretion along the nephron. Normally all the filtered HCO_3^- is reabsorbed and none appears in the urine. Changes in systemic acid-base [illegible] secrete H^+ and thus reabsorption.)

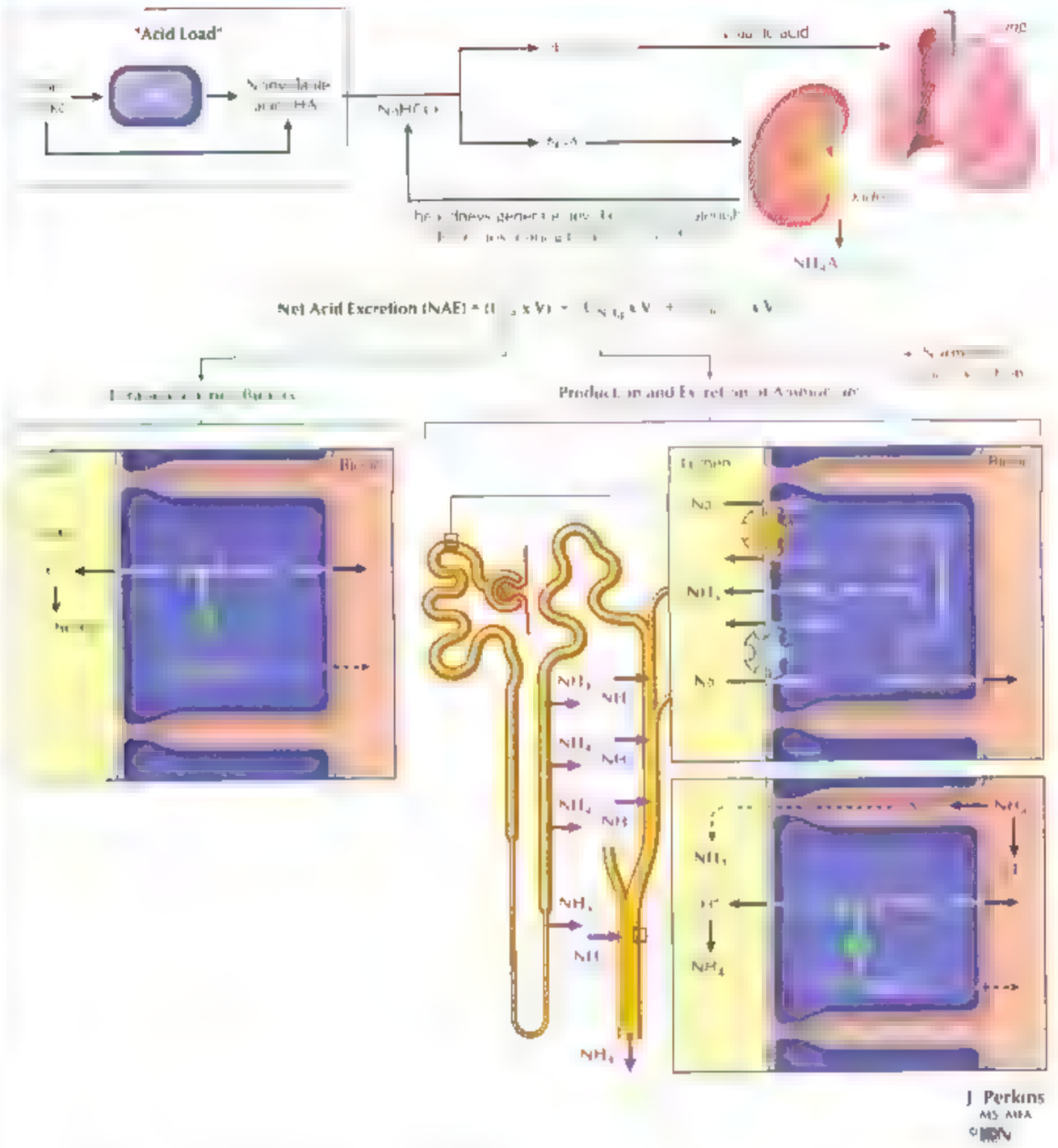


FIGURE 6.18 RENAL PRODUCTION OF NEW HCO_3^-

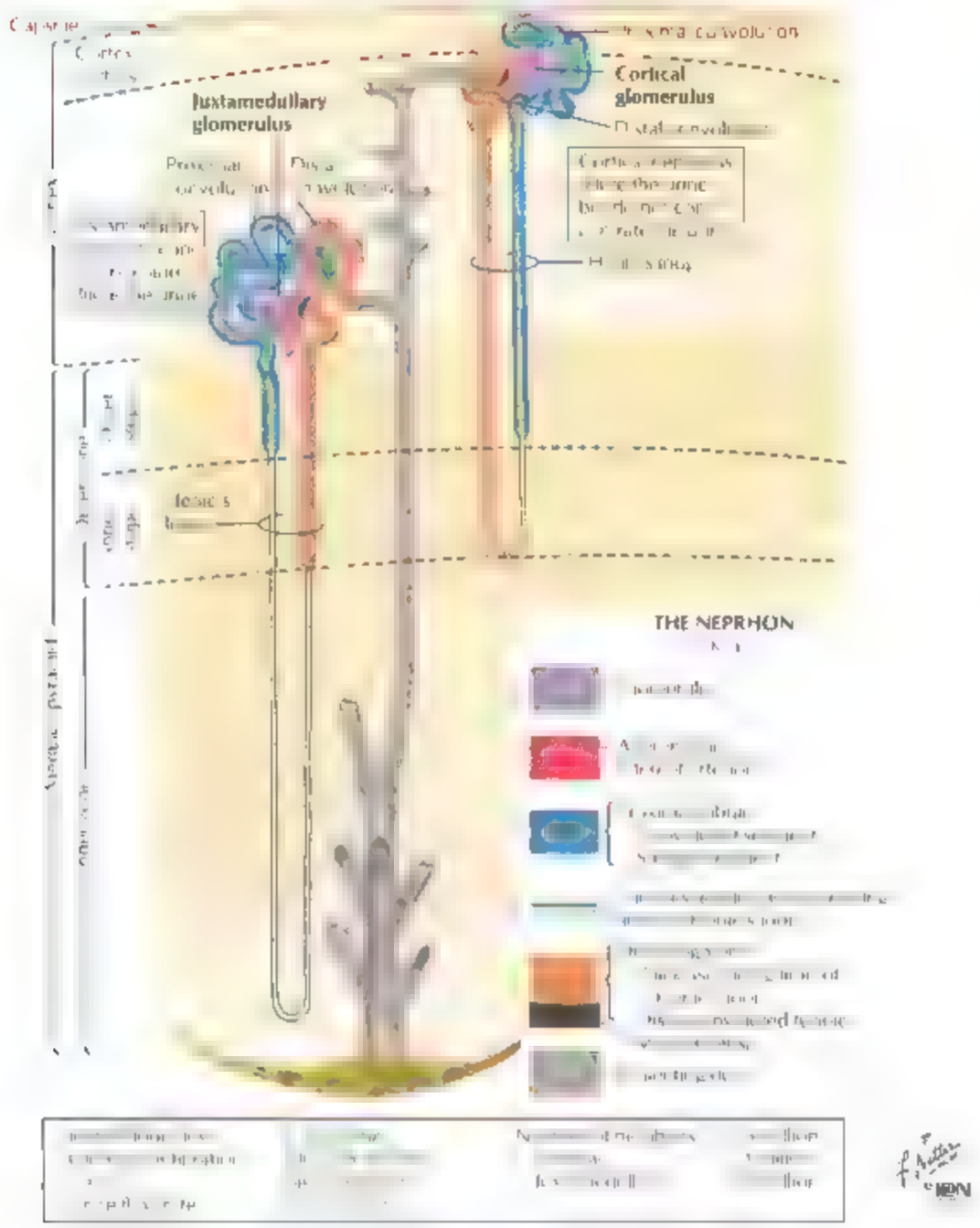


FIGURE 6.2 ANATOMY OF THE NEPHRON

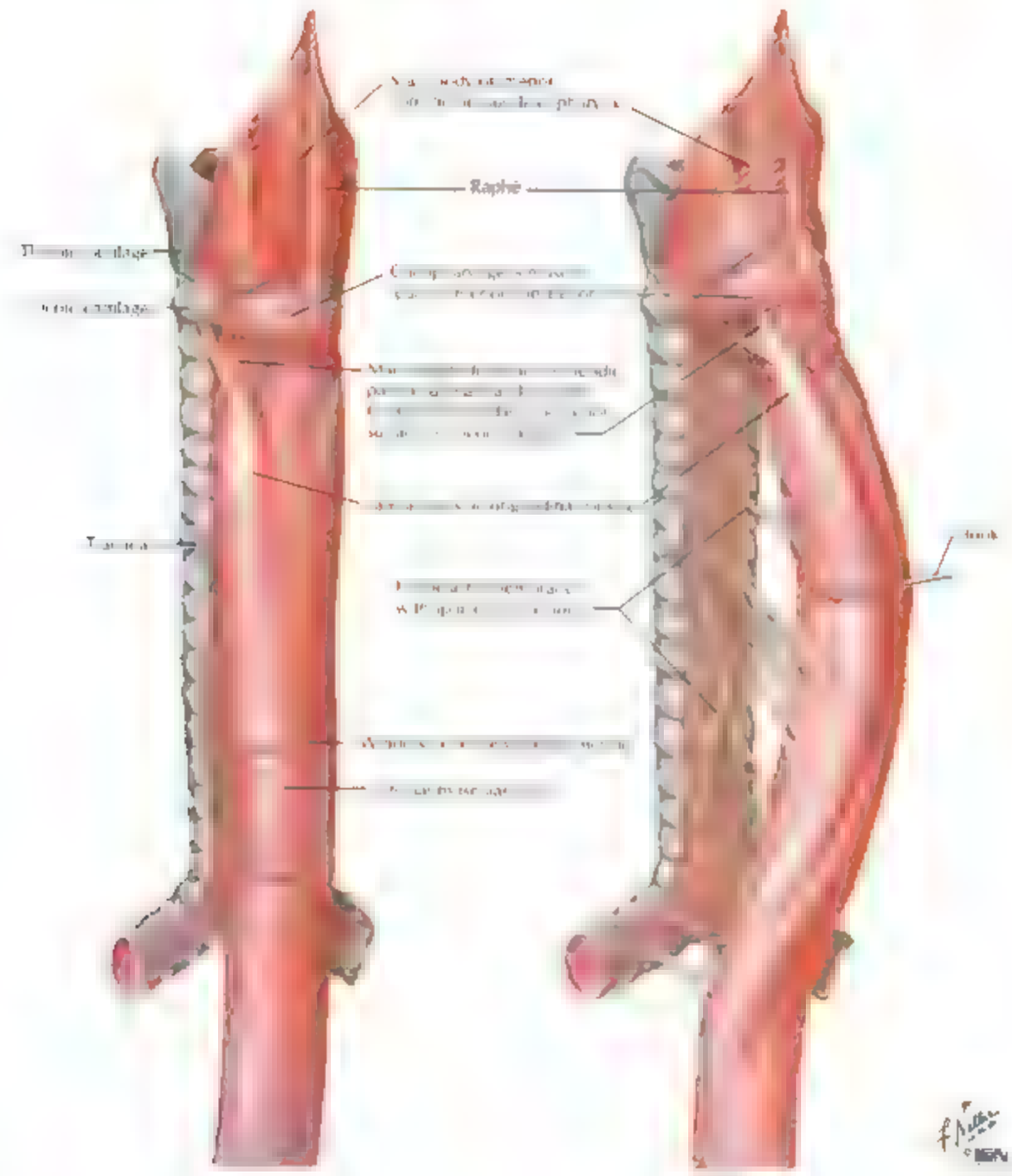


FIGURE 7.1 ESOPHAGUS

The esophagus is posterior to the trachea and extends from the oropharynx to the stomach. It propels food and fluid to the stomach by peristalsis. The muscle in the upper third of the esophagus is skeletal muscle, the lower third is smooth muscle, and the middle third is a mixed type. The muscle walls of the esophagus consist of an inner longitudinal and an outer circular layer.

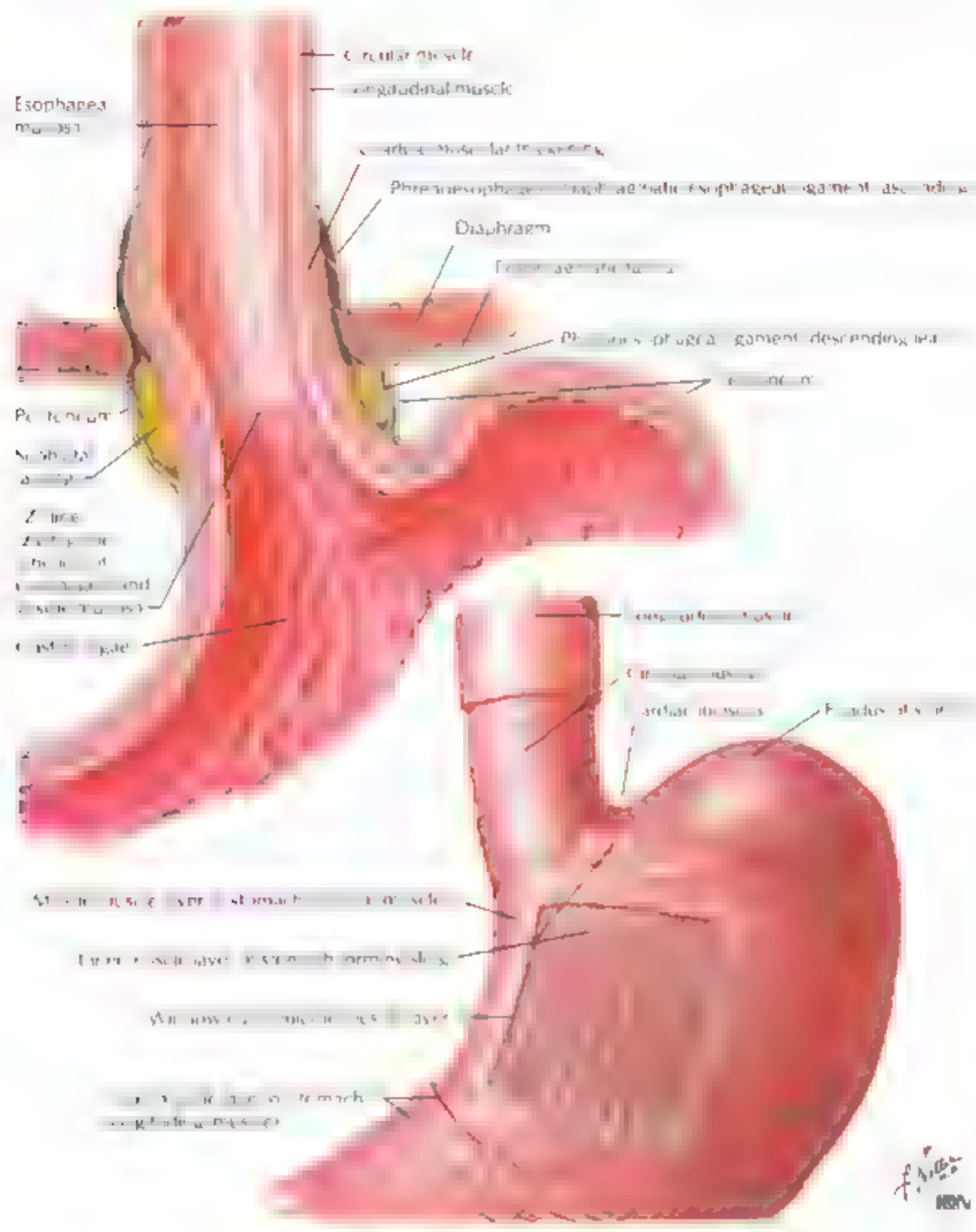


FIGURE 7.2 GASTROESOPHAGEAL JUNCTION

The smooth muscle of the lower esophagus forms the sphincter at the junction with the stomach and is normally contracted. This sphincter is called the lower esophageal sphincter (LES). The LES is where the esophagus passes through the diaphragm and is thus also called the esophageal hiatus. The
and the most proximal

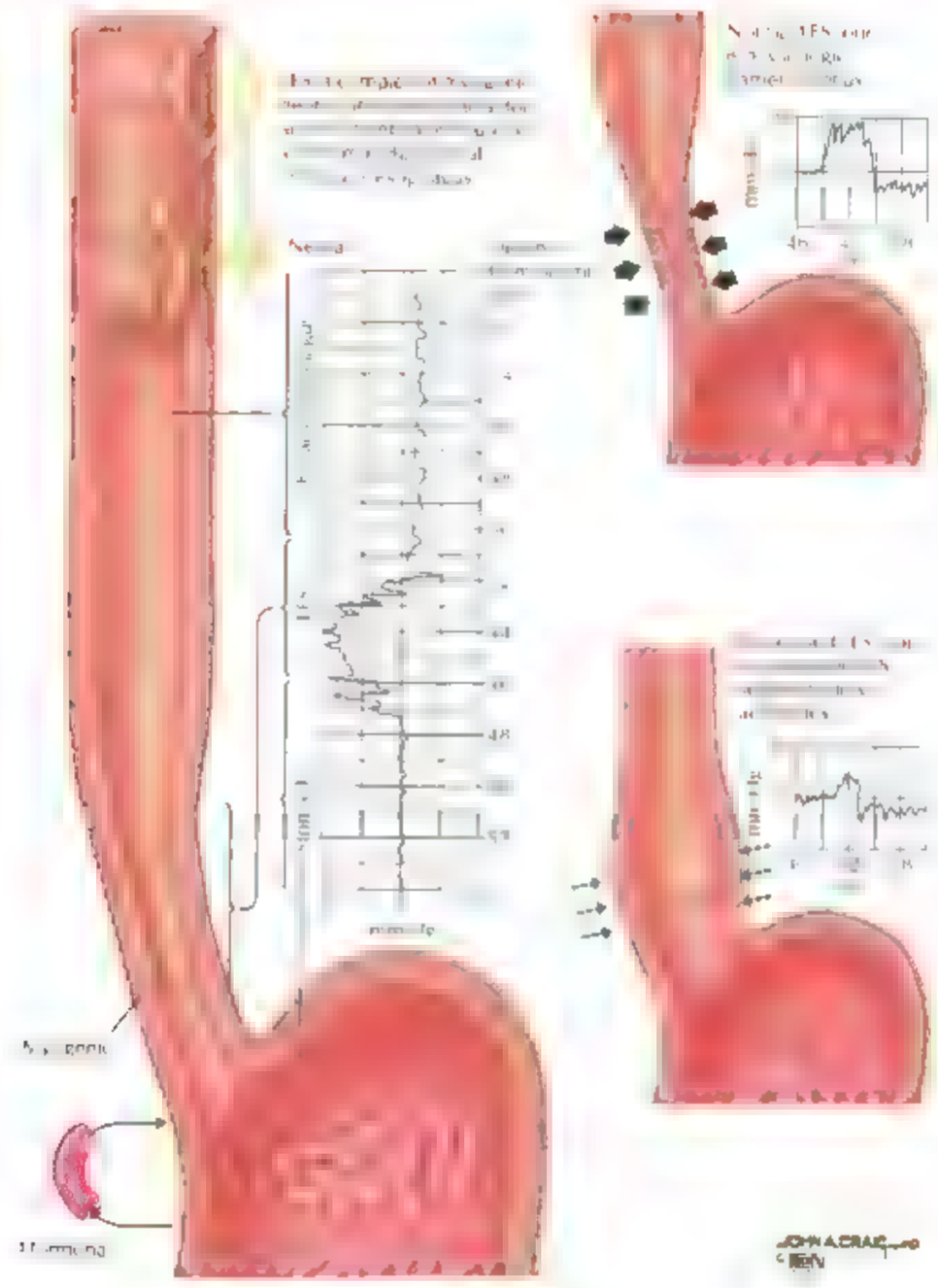


FIGURE 7.3 LOWER ESOPHAGEAL SPHINCTER

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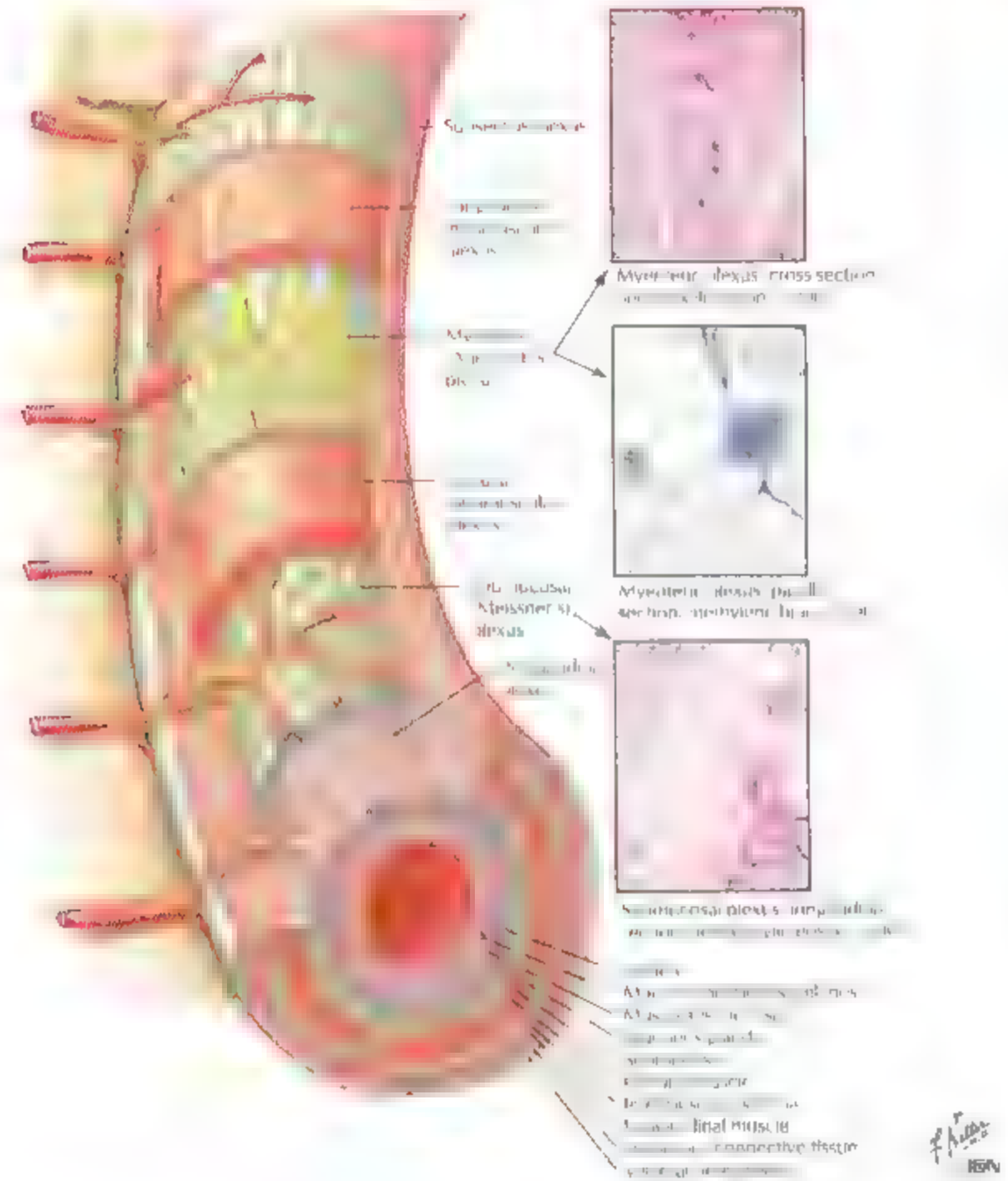

FIGURE 7.4 ENTERIC NERVOUS SYSTEM

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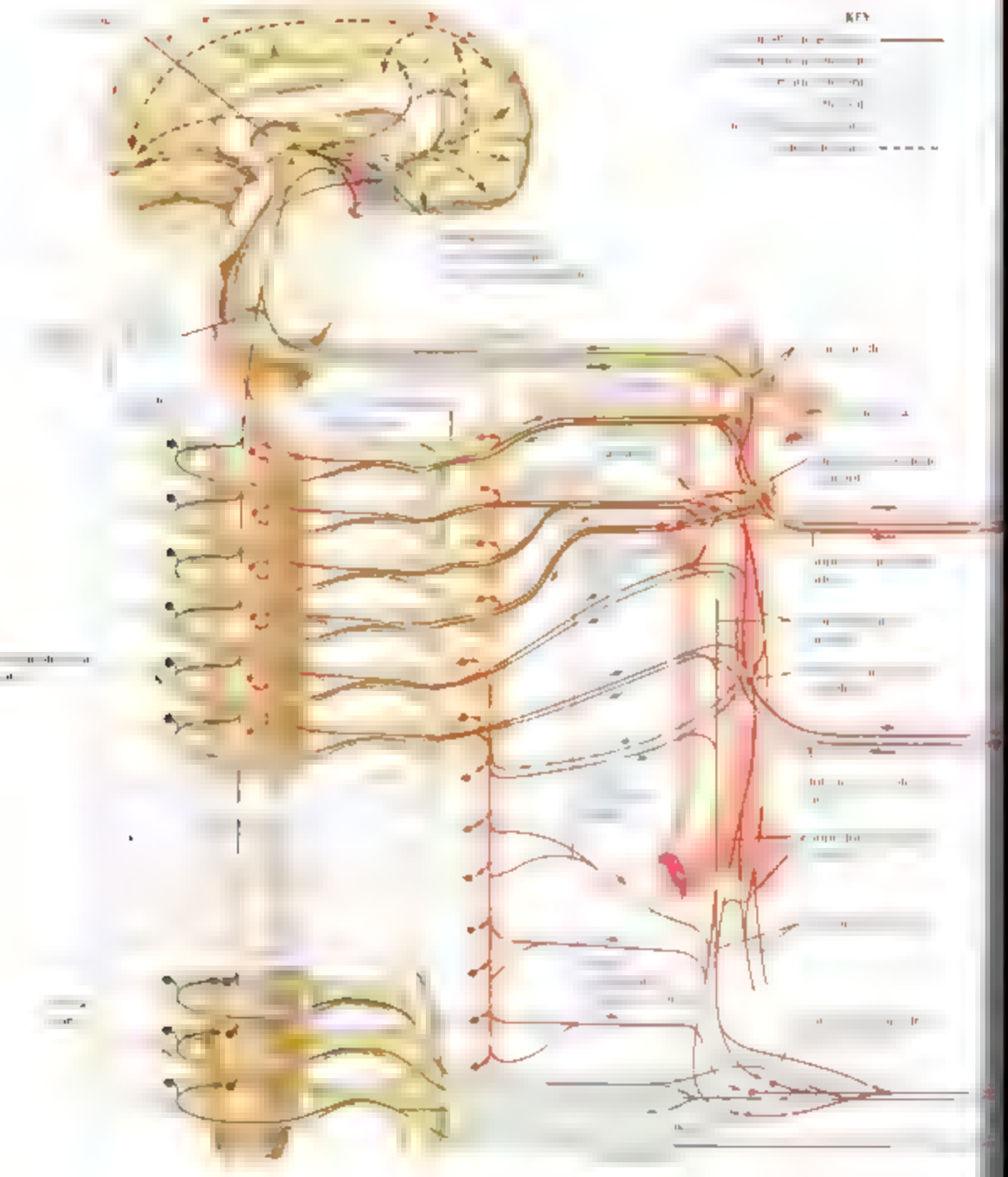

FIGURE 7.5 AUTONOMIC INNERVATION

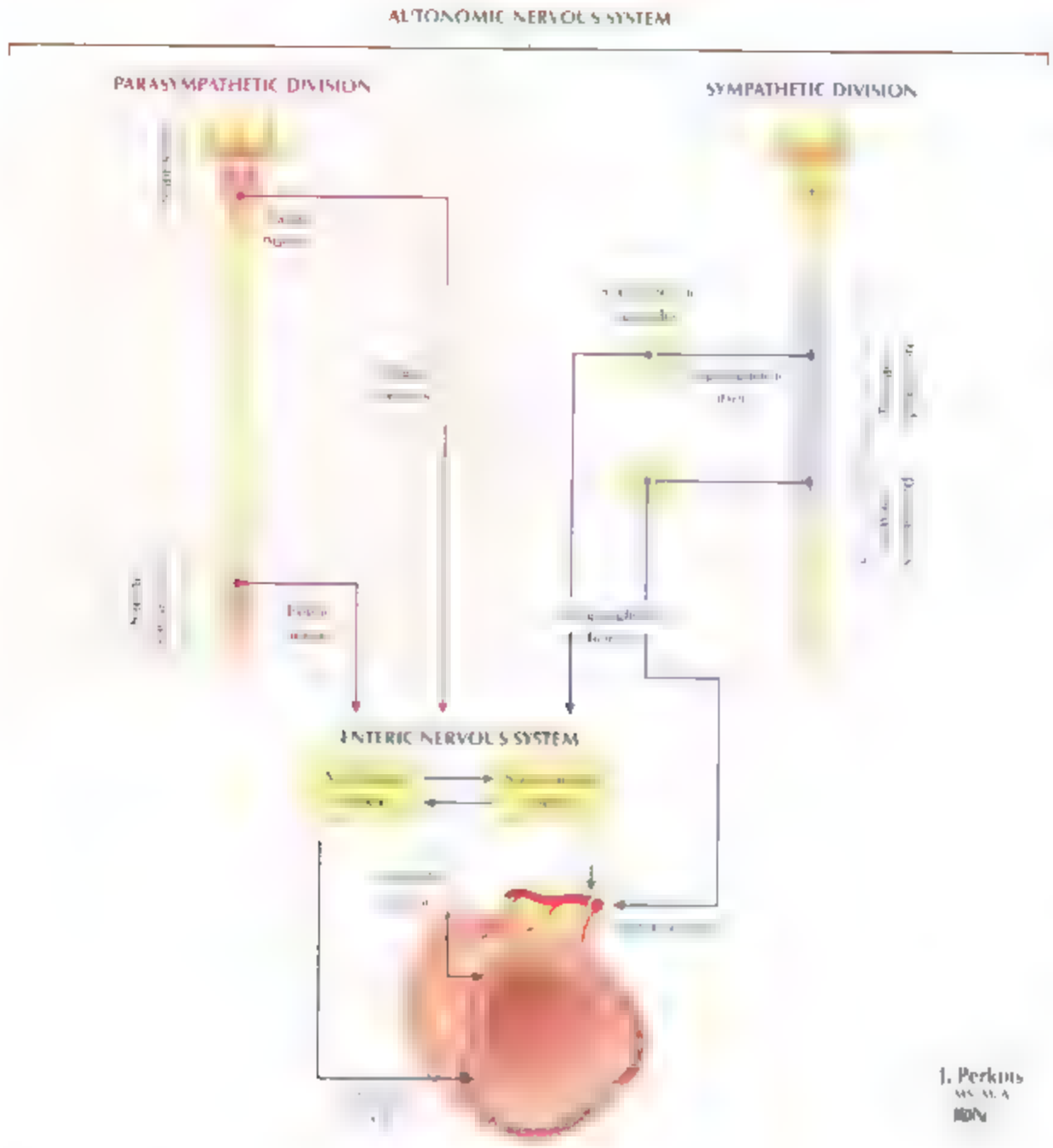

FIGURE 7.6 INTEGRATION OF AUTONOMIC AND ENTERIC NERVOUS SYSTEMS

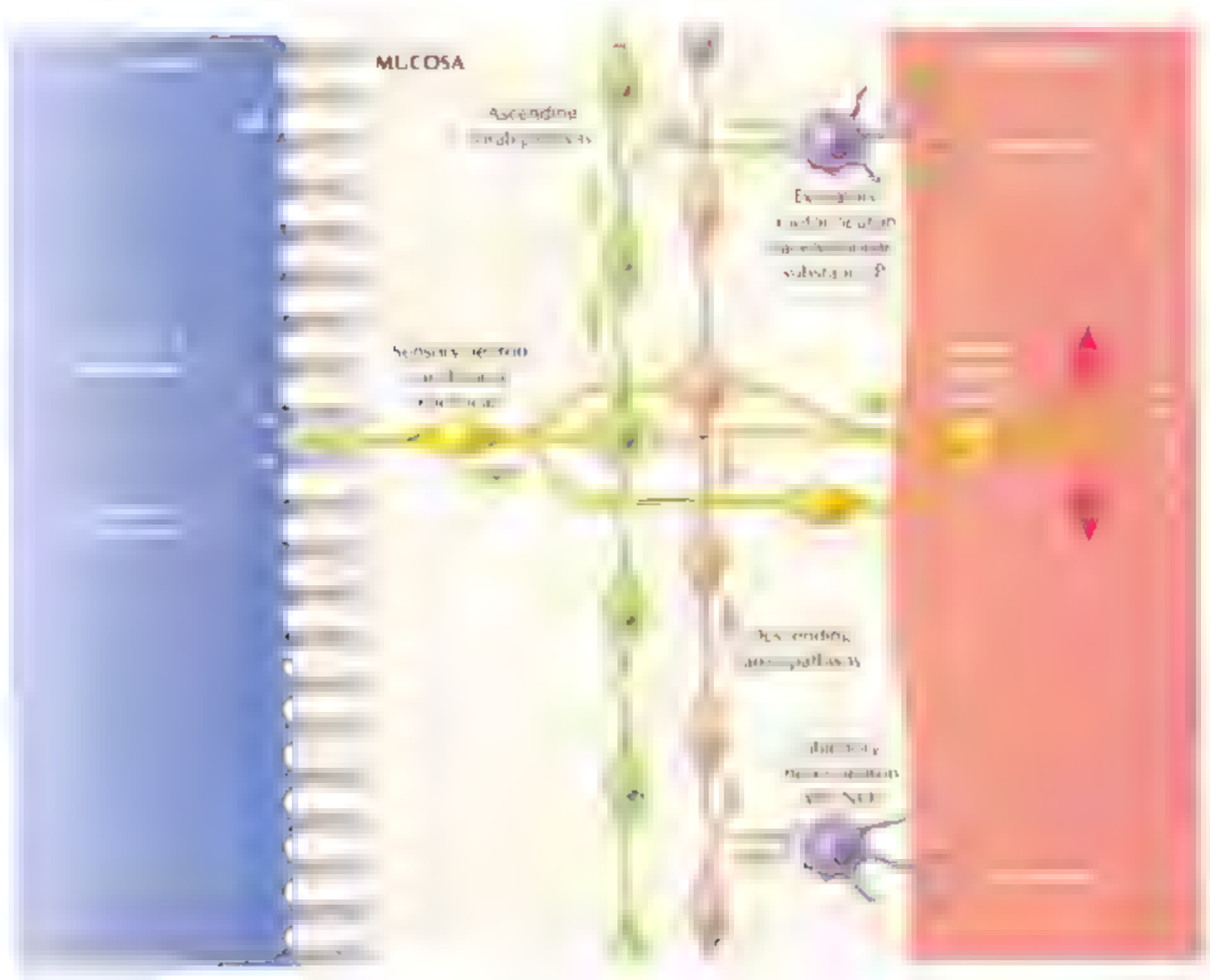

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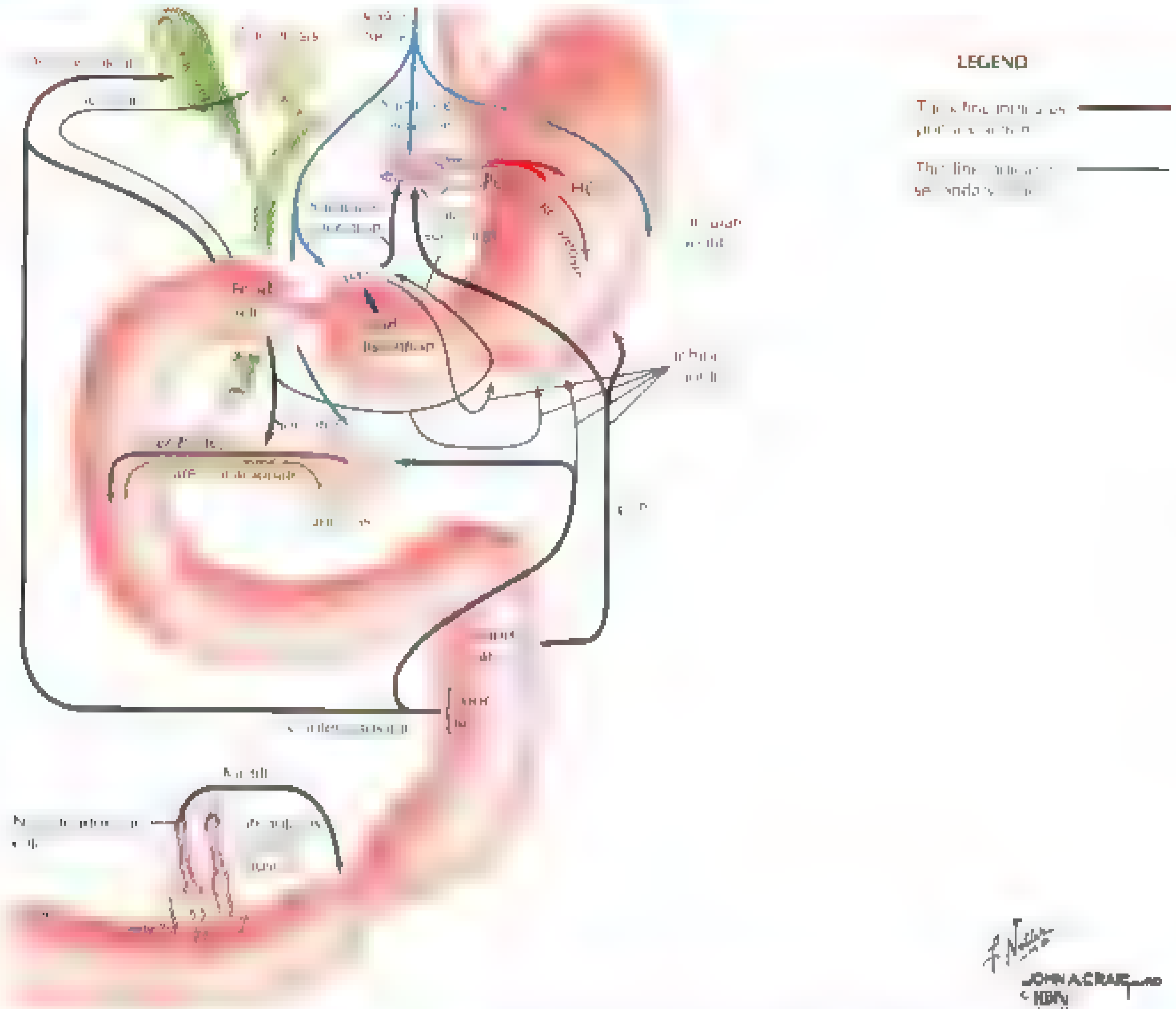
FIGURE 7.7 CONTROL OF PERISTALSIS



Hormone	Neuroendocrine Cell Type and Location	Stimulus for Secretion	Primary Action	Other Actions
[illegible]	G cell [illegible]	[illegible]	Stimulate HCl secretion	Inhibit gastric emptying
[illegible]	S cell Duodenum	[illegible]	[illegible] secretion	[illegible] and stimulates bile duct secretion [illegible]
[illegible]	[illegible] cell [illegible]	[illegible]	[illegible] the gallbladder	[illegible]
[illegible]	K cell [illegible]	[illegible]	[illegible]	[illegible]
Motilin	M cell Duodenum, jejunum		[illegible]	

FIGURE 7.8 MAJOR GI HORMONES

[illegible] sympathetic [illegible] vagus nerve [illegible] and hormonal [illegible] have been [illegible] a large number of other candidate hormones [illegible] endocrine cells [illegible] the stomach and intestines [illegible] a role in regulating and coordinating GI [illegible] [illegible] listed [illegible] the other secondary [illegible] hormones are summarized. The [illegible] electric complex (MMC) [illegible] period of [illegible] tract by moving residual [illegible] particles distally.

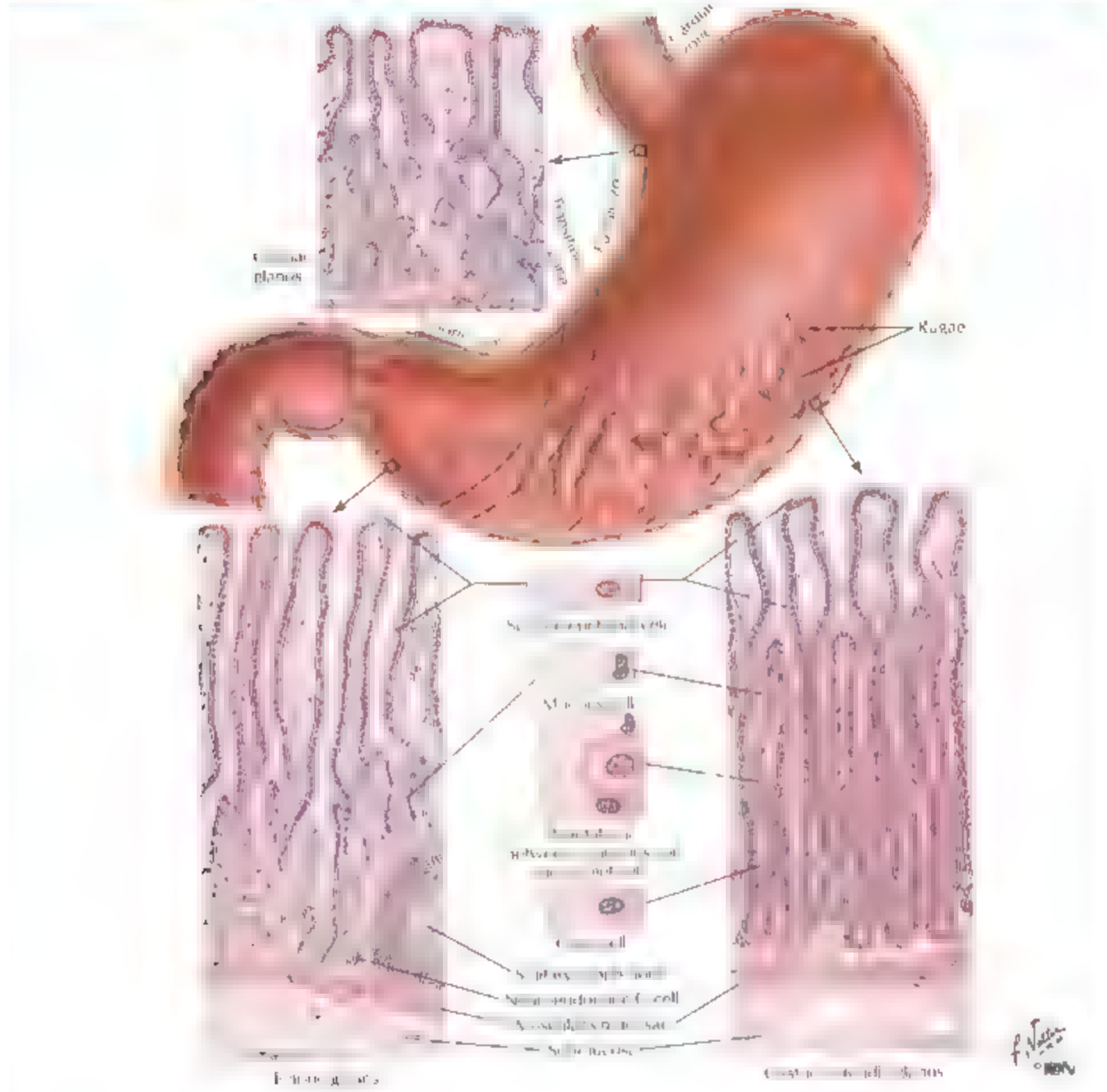


FIGURE 7.9 STRUCTURE OF THE STOMACH

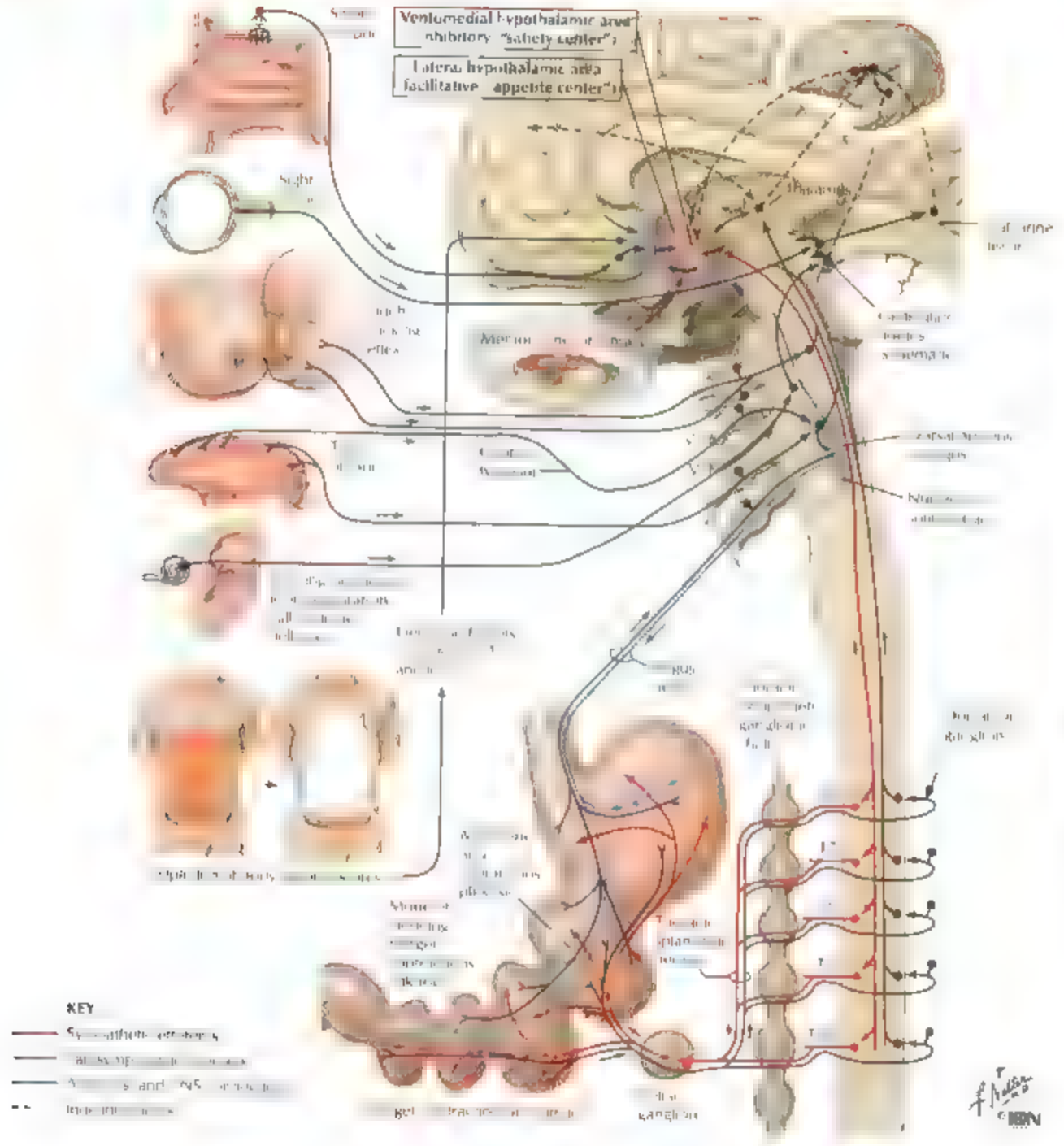
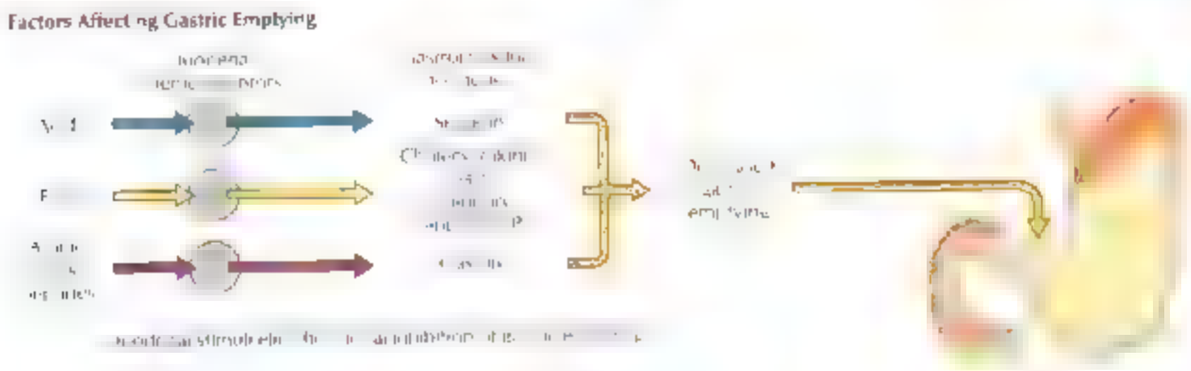


FIGURE 7.10 APPETITE AND HUNGER

The sensations of hunger and satiety are controlled by complex neural pathways involving several brain regions. Activated hunger centers produce the sensation of hunger. Although the [illegible] appetite (the appetite as known) plays a major role in food intake, hunger and food intake. When [illegible] stressed, the liver stores [illegible] glucagon-like peptide are released from neuroendocrine cells in the intestine. These hormones suppress appetite and give the sensation of satiety. In the fasted state, the levels of these hormones are low. Long-term regulation of body mass may involve the hormone leptin, which is produced by fat cells. When a person's weight [illegible] is increased and stomach is [illegible] the hypothalamus suppresses appetite. When body fat stores are depleted, leptin levels are low.



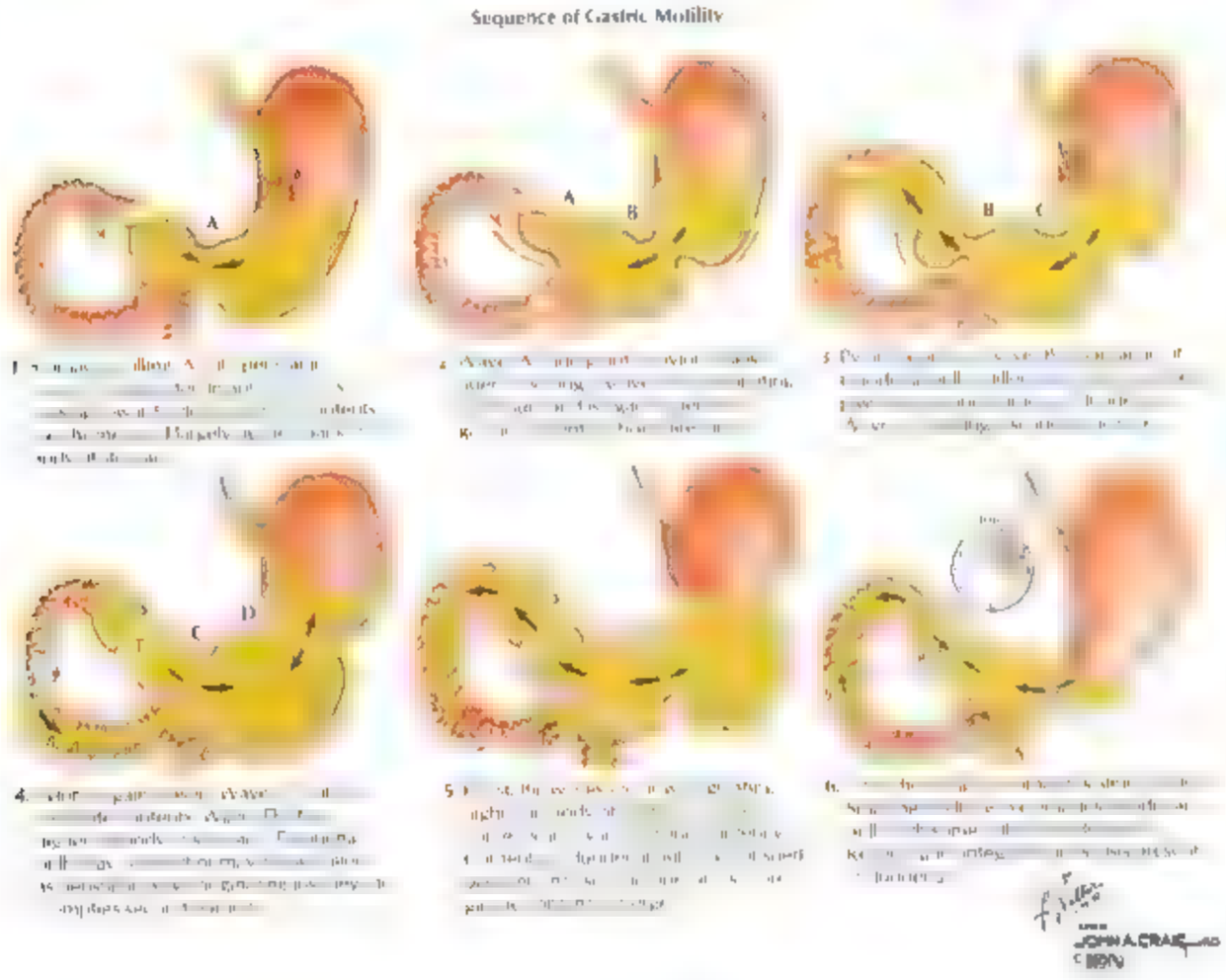


FIGURE 7.11 GASTRIC MOTILITY

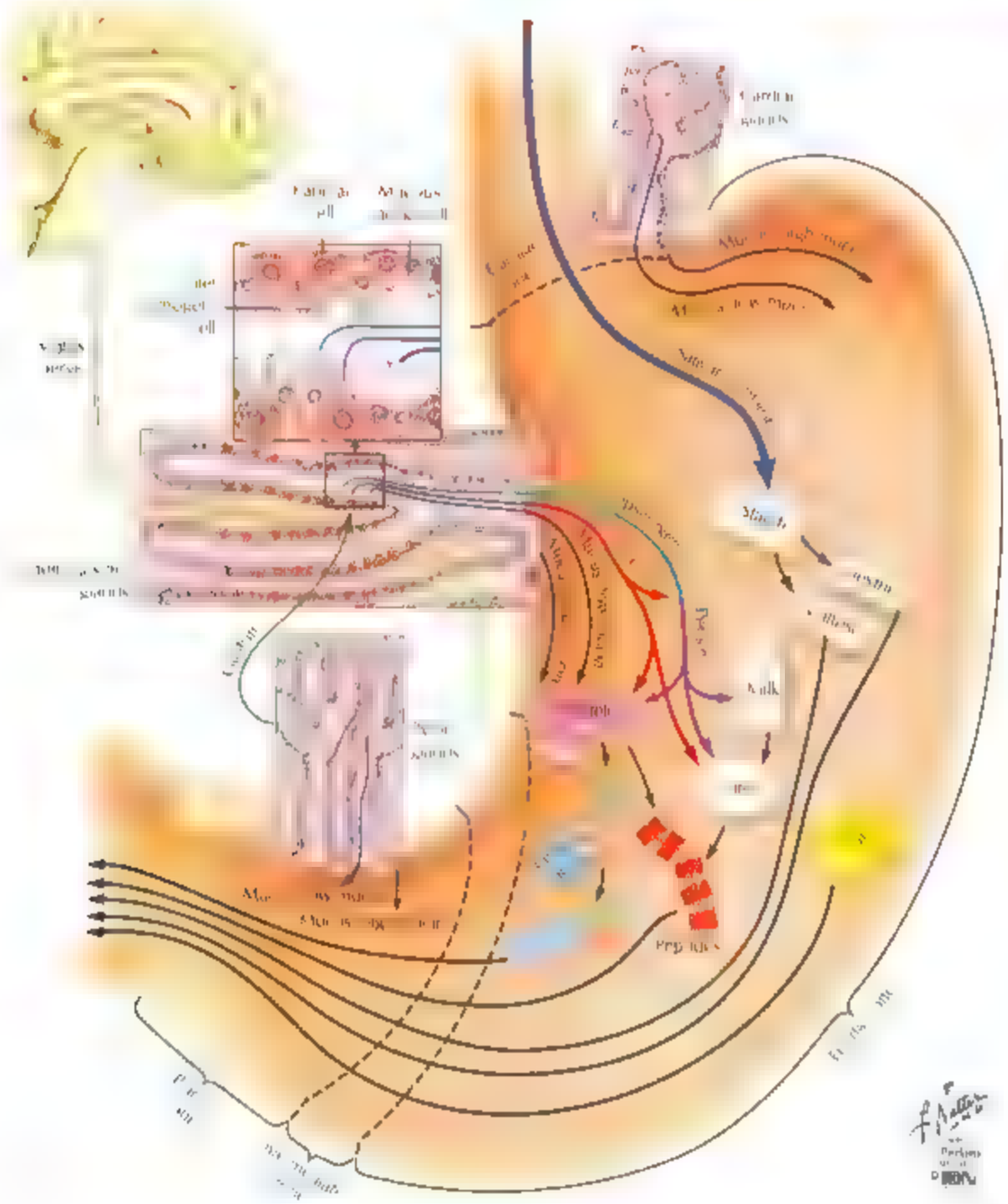


FIGURE 7.12 GASTRIC DIGESTIVE FUNCTION

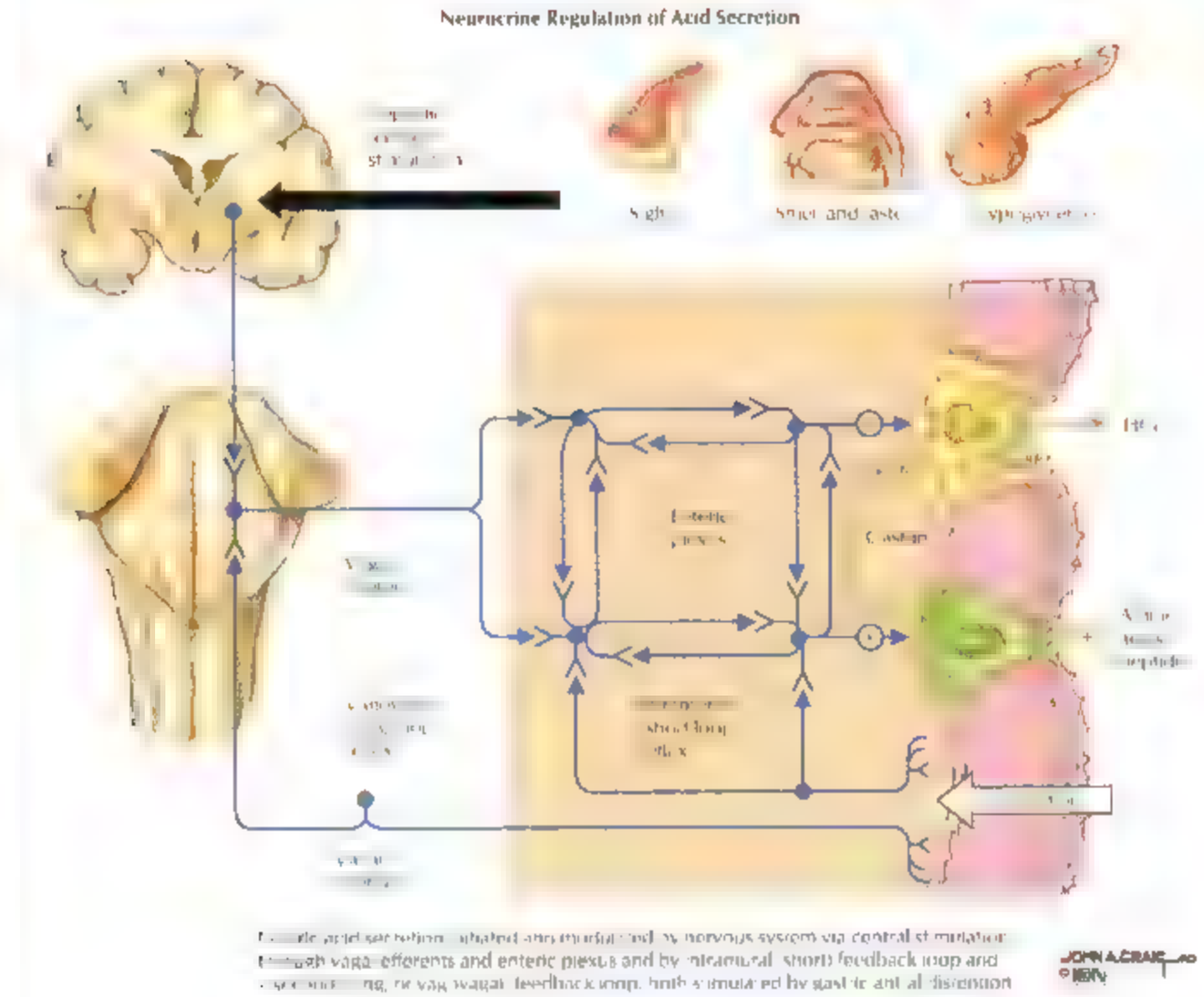
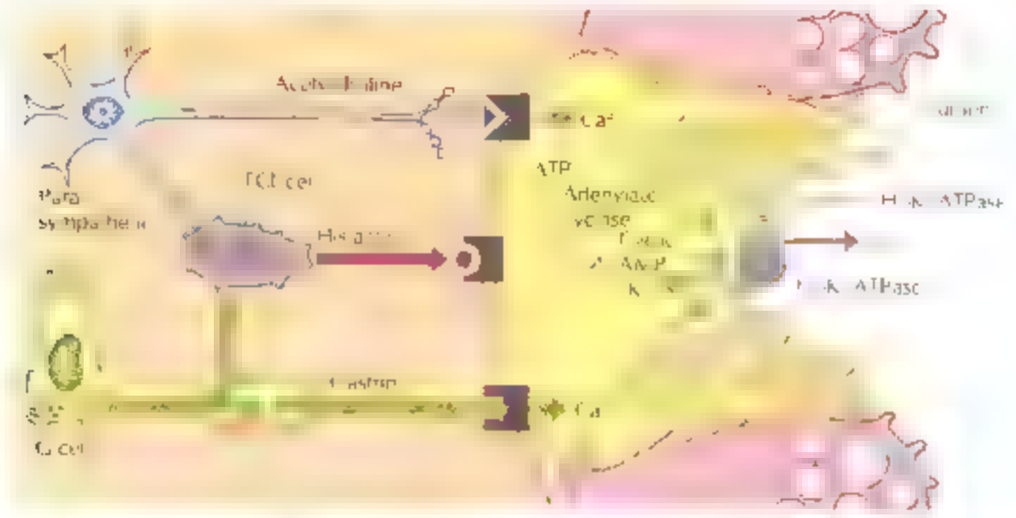


FIGURE 7.13 VAGAL CONTROL OF GASTRIC SECRETION



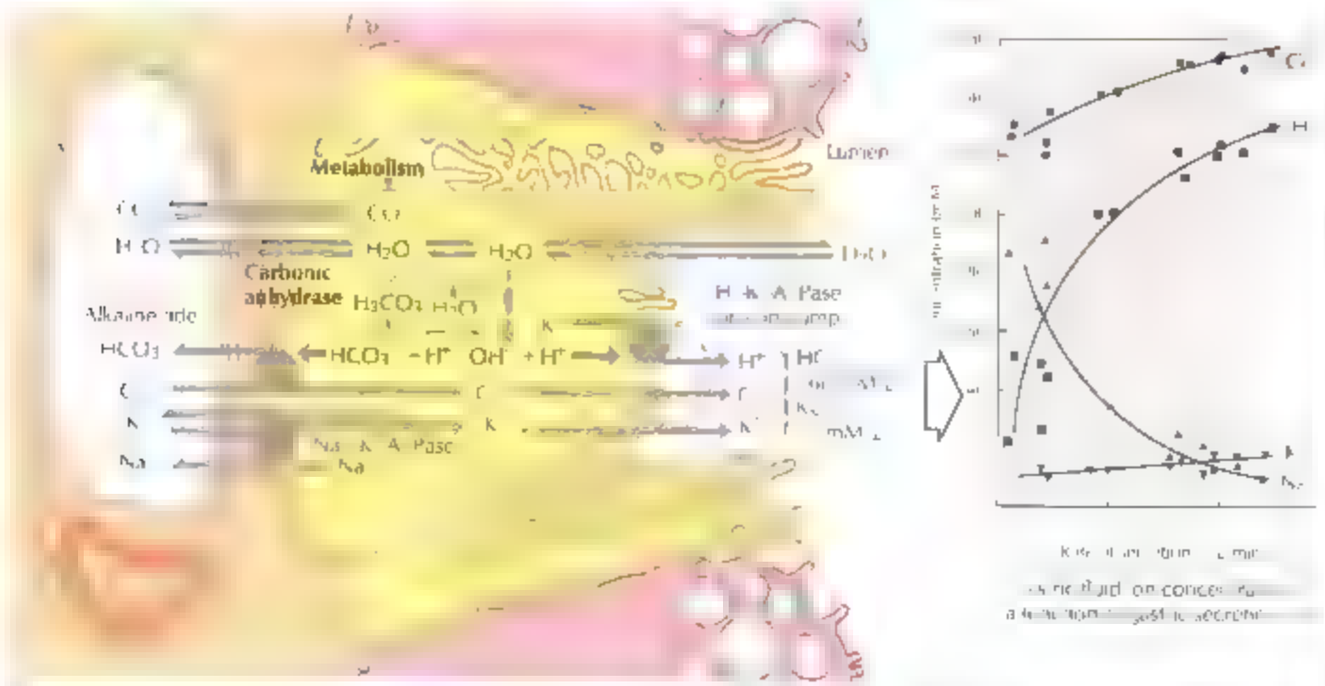


FIGURE 7.14 REGULATION OF PARIETAL CELL FUNCTION

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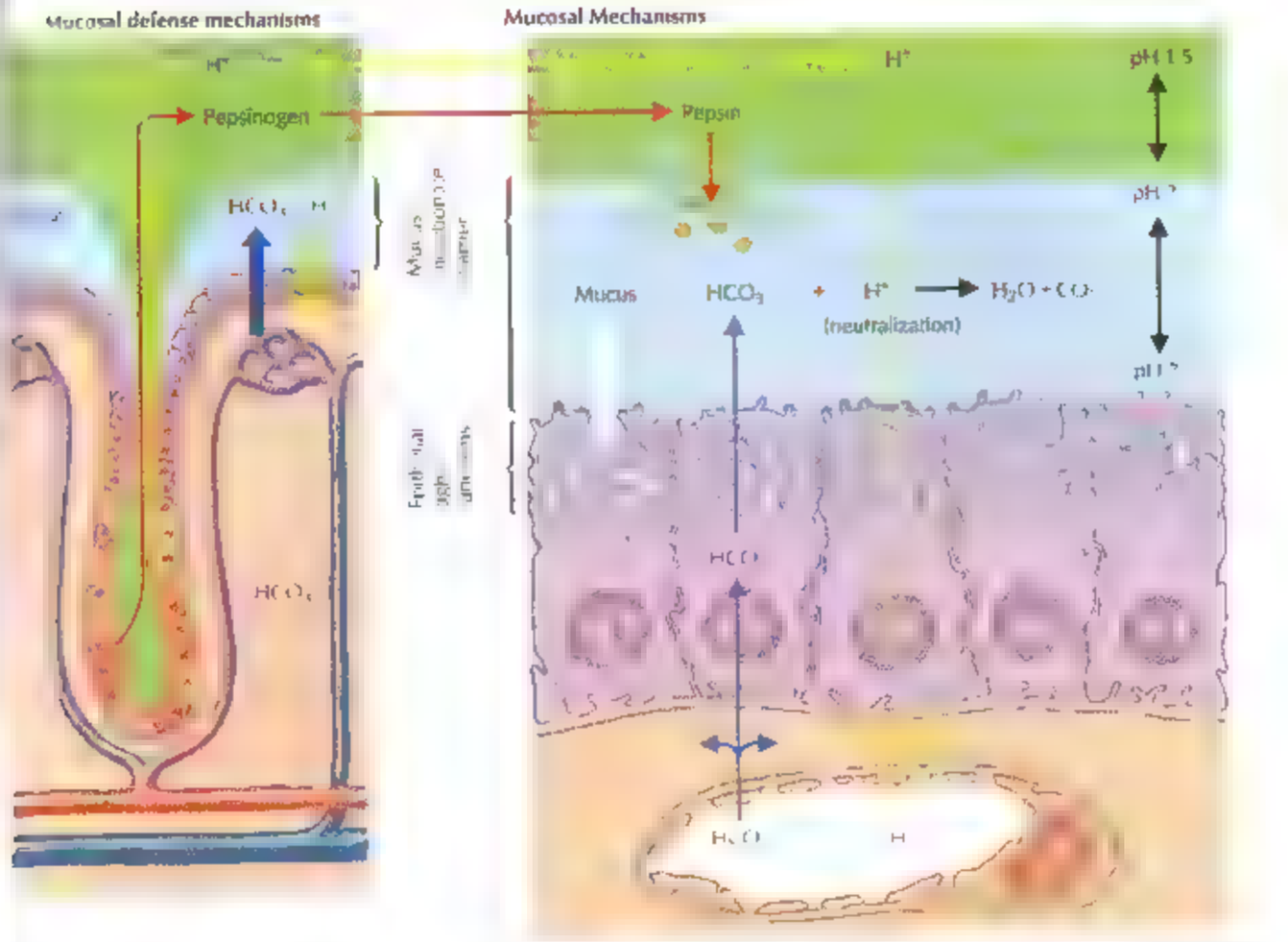

Gastric mucosa and submucosa protected from chemical injury by mucus-bicarbonate surface barrier that neutralizes gastric H^+ and by epithelial "tight junctions" that prevent H^+ access to subepithelial tissue

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FIGURE 7.15 MUCOSAL DEFENSE MECHANISMS

The high-mucin-containing mucus produced by the surface epithelial cells protects the stomach from abrasion and provides a relatively alkaline environment for the epithelial cells. This mucus layer traps bicarbonate and remains relatively stable, providing a pH gradient above the surface epithelium, compared to a pH of 1–2 in the gastric lumen.

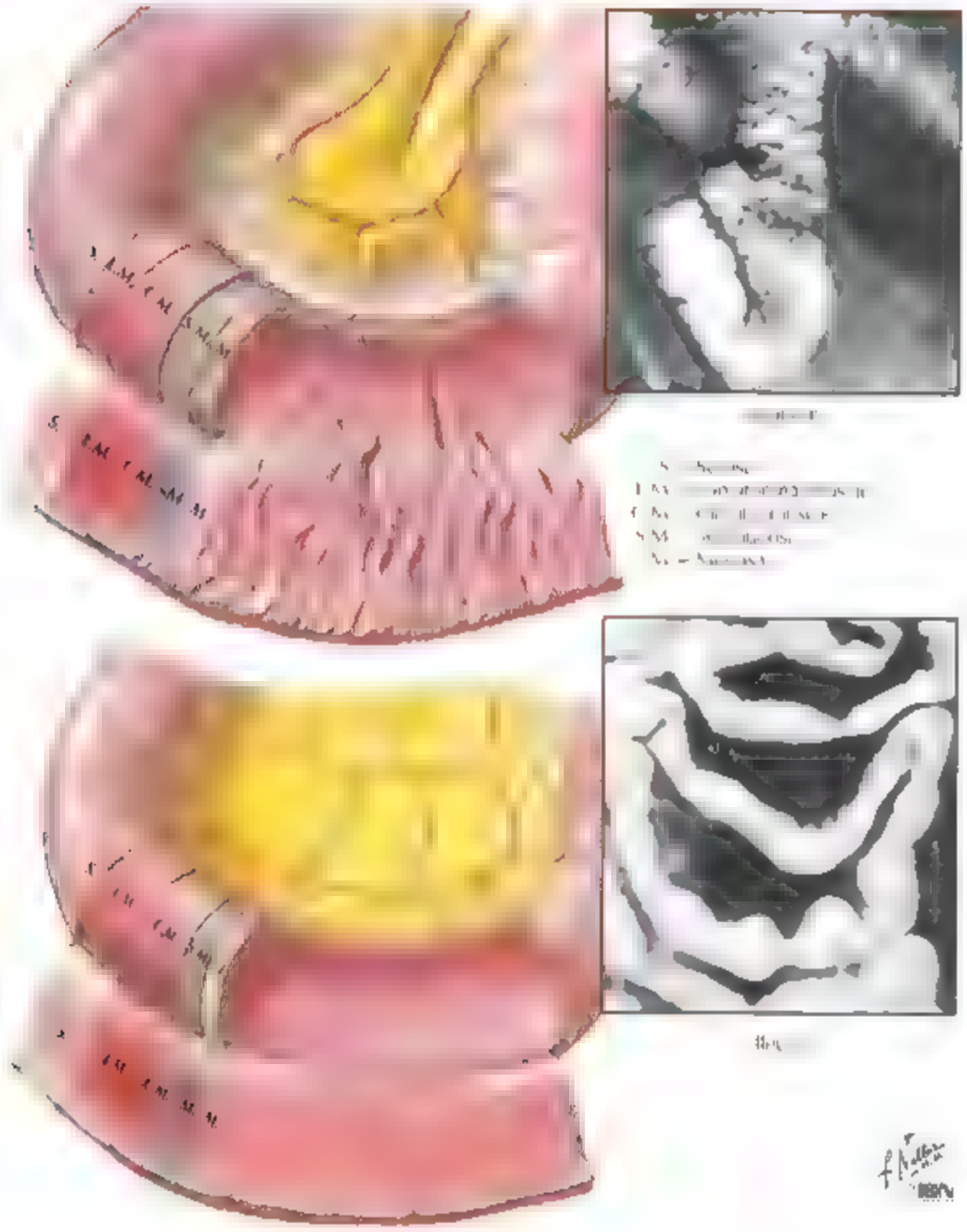


FIGURE 7.16 SMALL INTESTINE STRUCTURE

The top diagram identifies and locates the parts of the small intestine. A cross-section of the duodenum is shown in the middle segment, where villi and microvilli are also visible. The bottom diagram shows the jejunum as a large diameter tube with [illegible] villi [illegible] the ileum as a small diameter tube with [illegible] villi. The photomicrographs on the right show the mucosal surface of the jejunum and ileum, respectively, at low power. The absorptive surface of the jejunum is evident. Goblet cells are also visible.

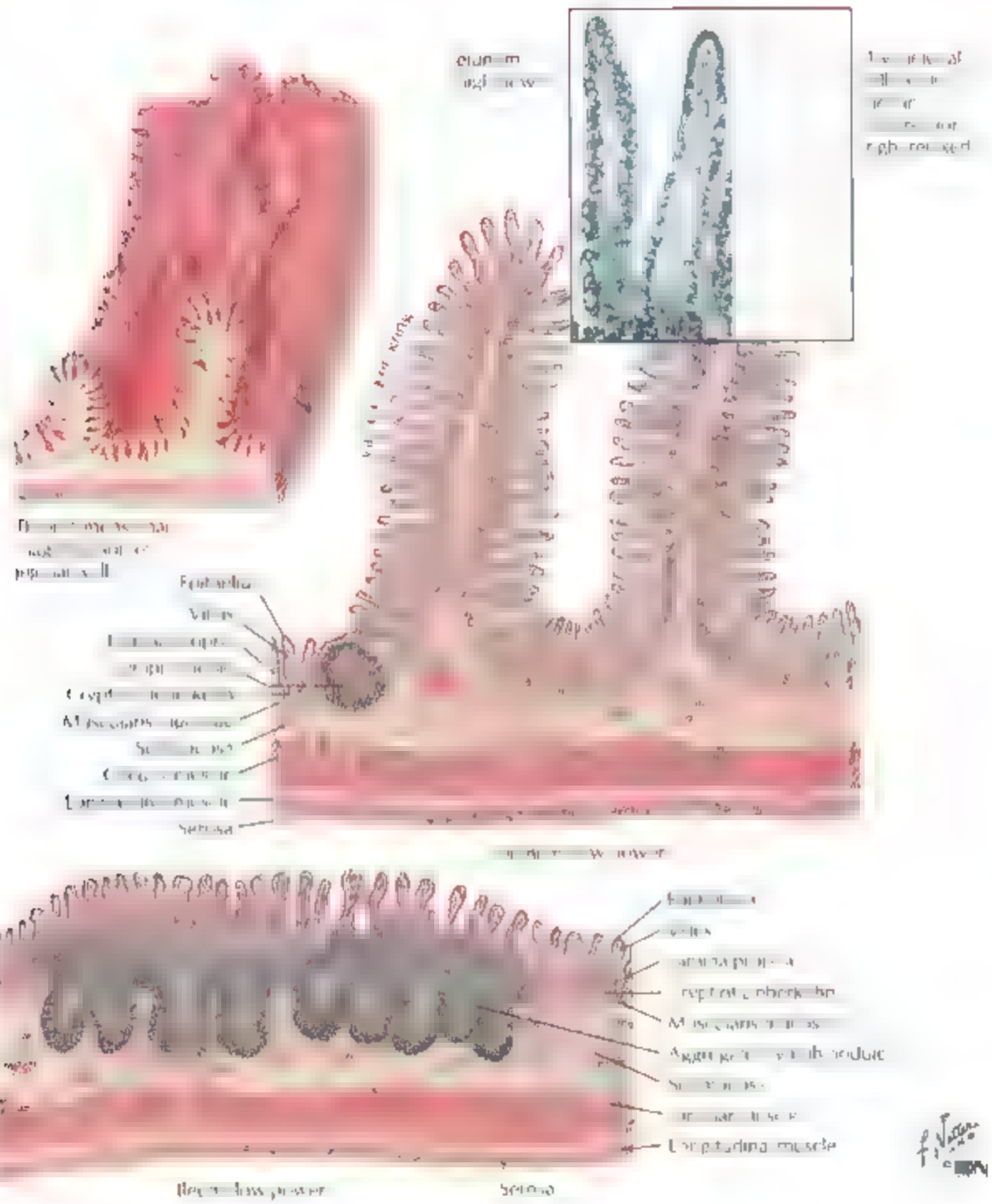


FIGURE 7.17 SMALL INTESTINE MICROSCOPIC STRUCTURE

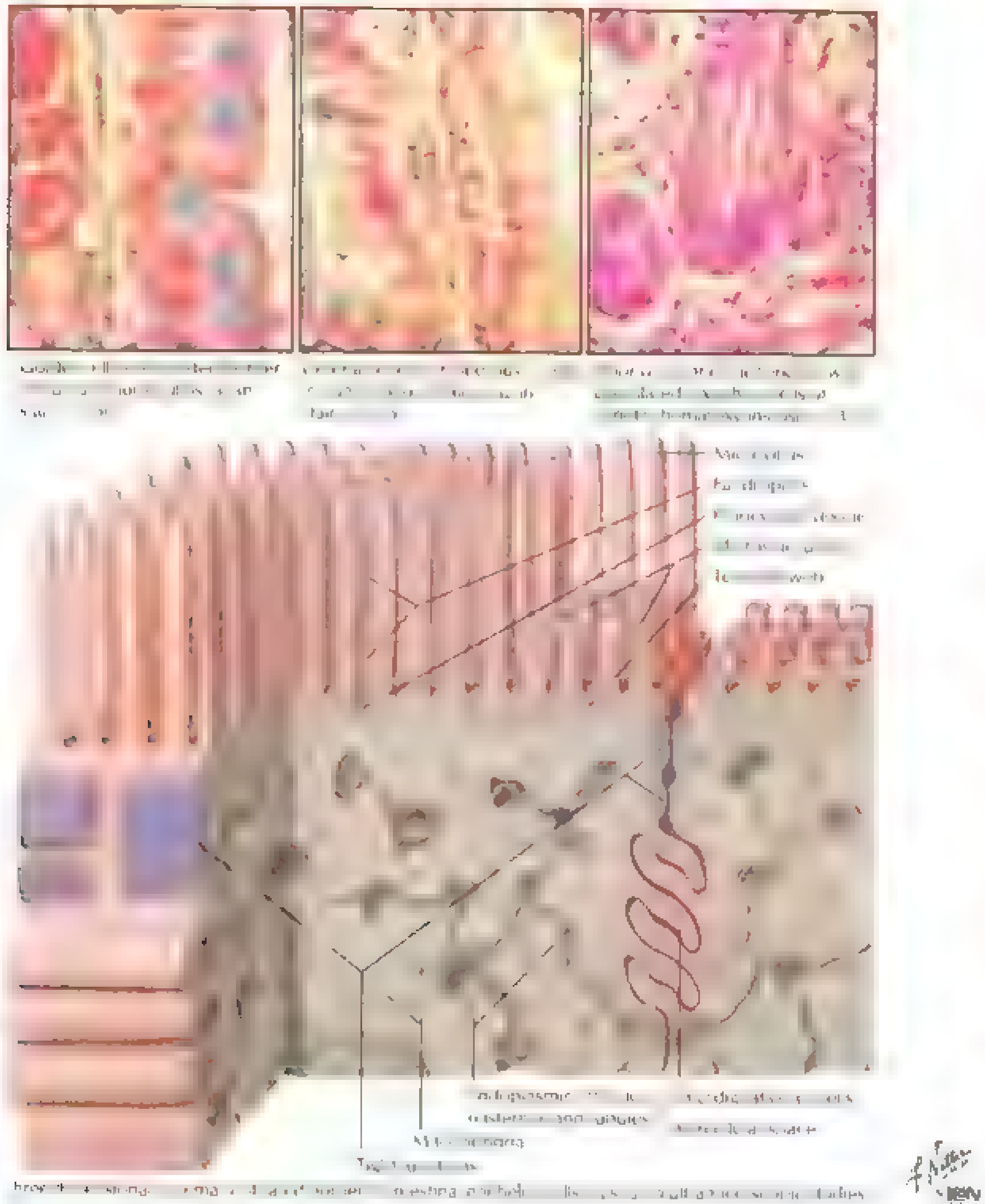


Figure 7.18 Epithelium of the Small Intestine

The villi are lined with a single layer of columnar epithelial cells [illegible] enterocytes. The apical membrane of the enterocytes [illegible] numerous microvilli. [illegible] and the secretory [illegible] the [illegible]. Interspersed among the enterocytes are goblet [illegible] secrete mucus. The crypts of Lieberkühn are [illegible] at the base of the [illegible] and are the site where actively dividing cells are found. The new[illegible] up the villus over [illegible] days [illegible] into the lumen. The crypts also contain Paneth [illegible] lysozyme.

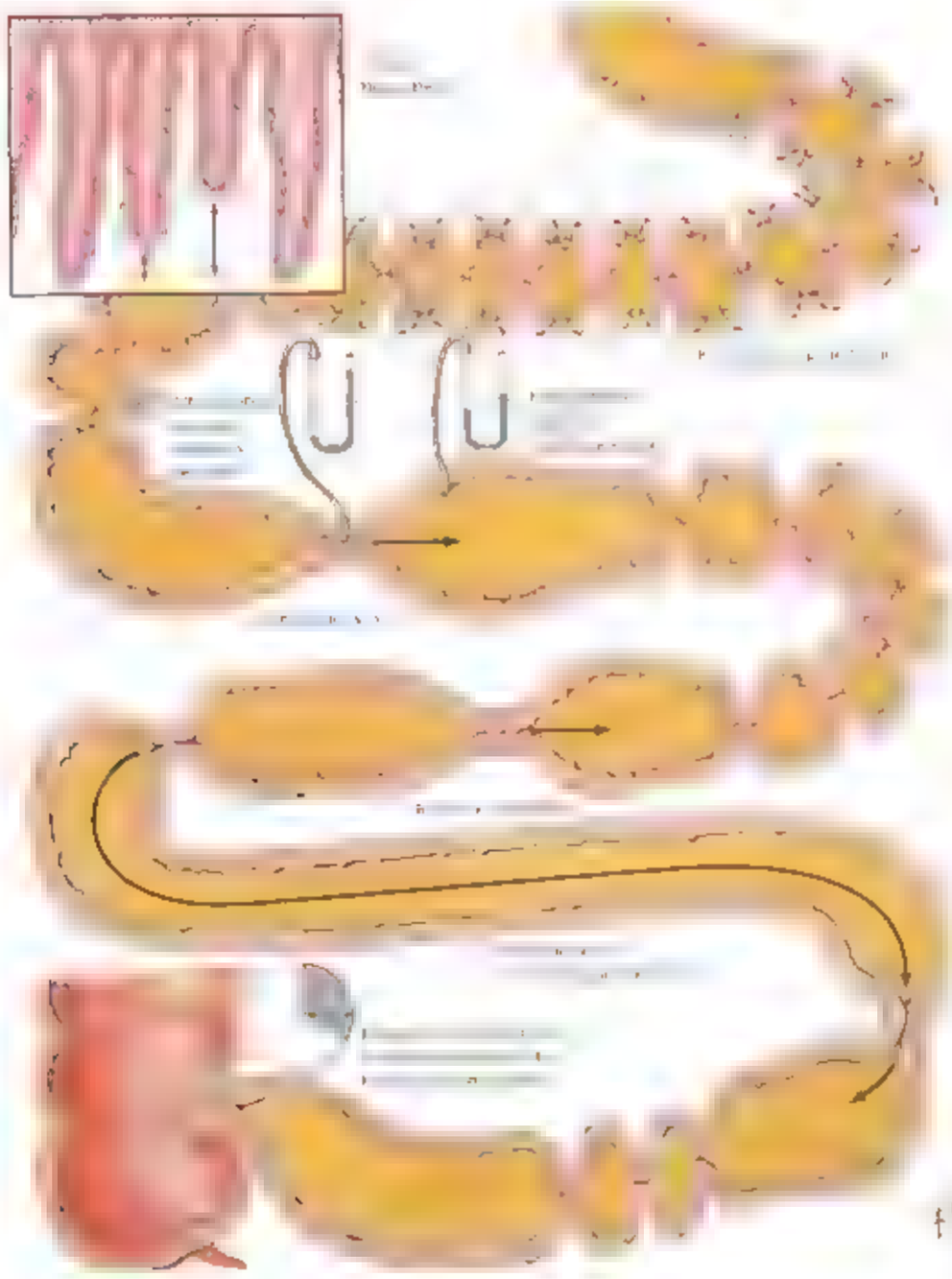


FIGURE 7.19 MOTILITY OF THE SMALL INTESTINE

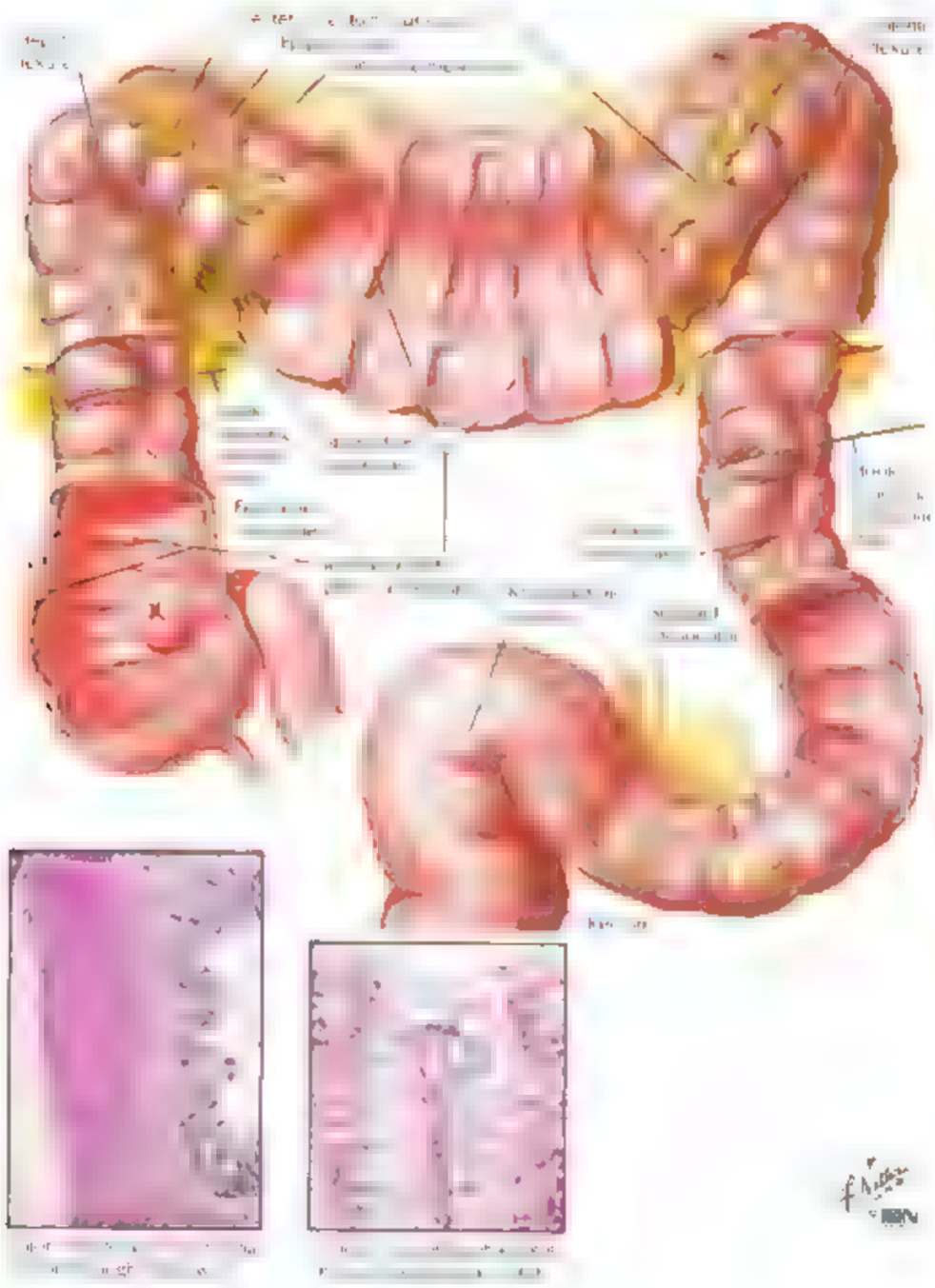


FIGURE 7.20 LARGE INTESTINE STRUCTURE

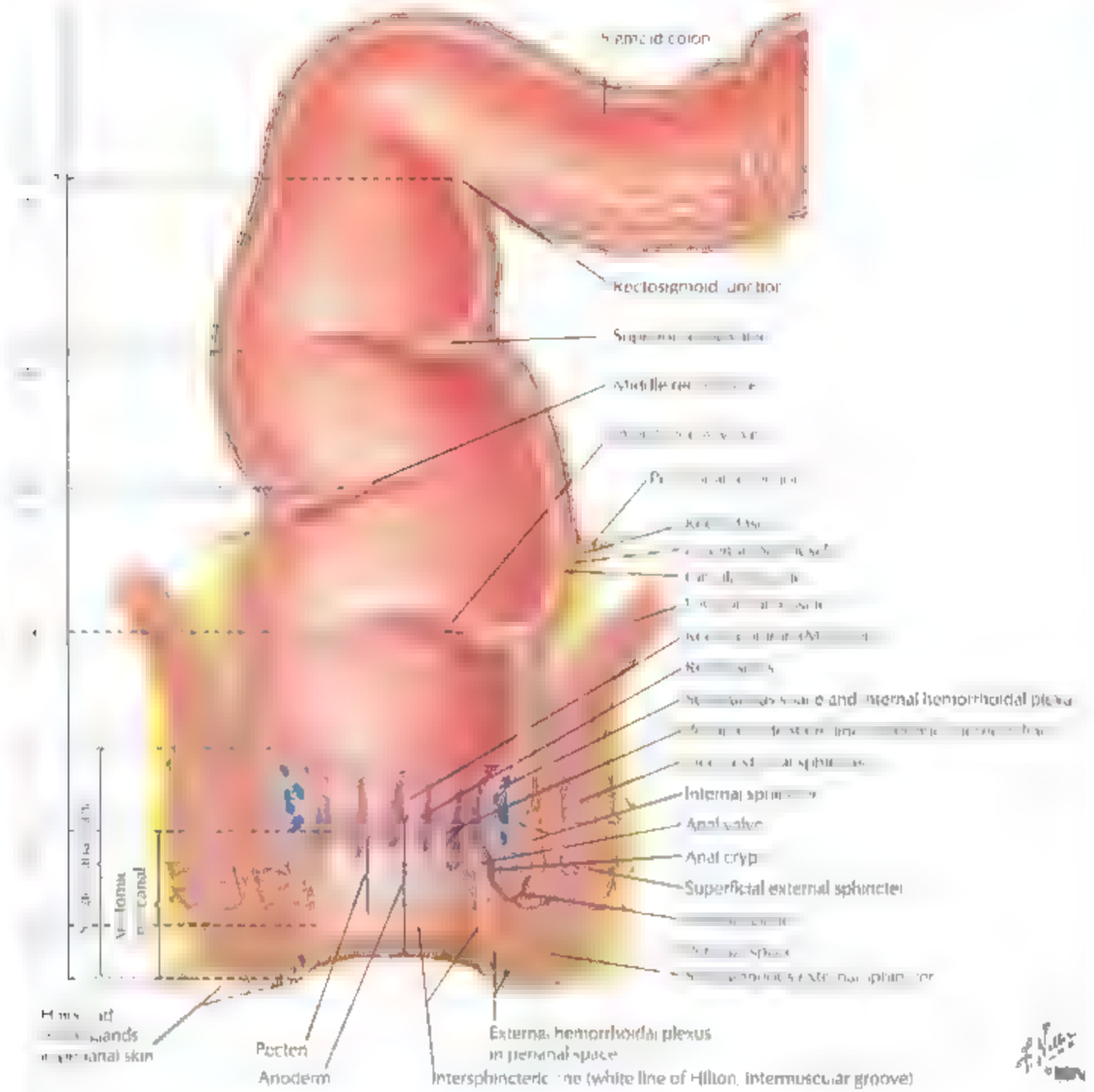


FIGURE 7.21 STRUCTURE OF THE RECTUM AND ANAL CANAL

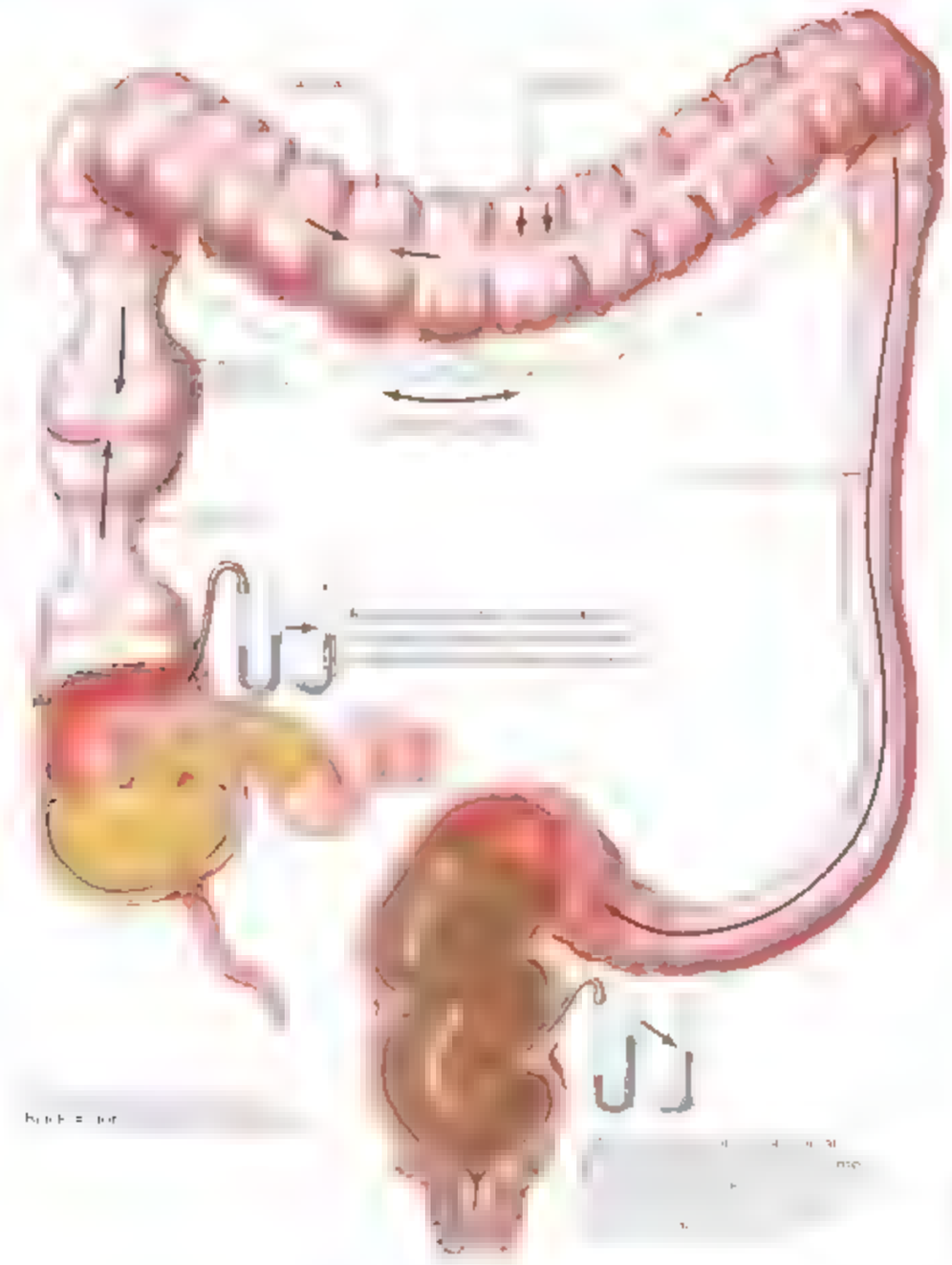


FIGURE 7.22 COLONIC MOTILITY

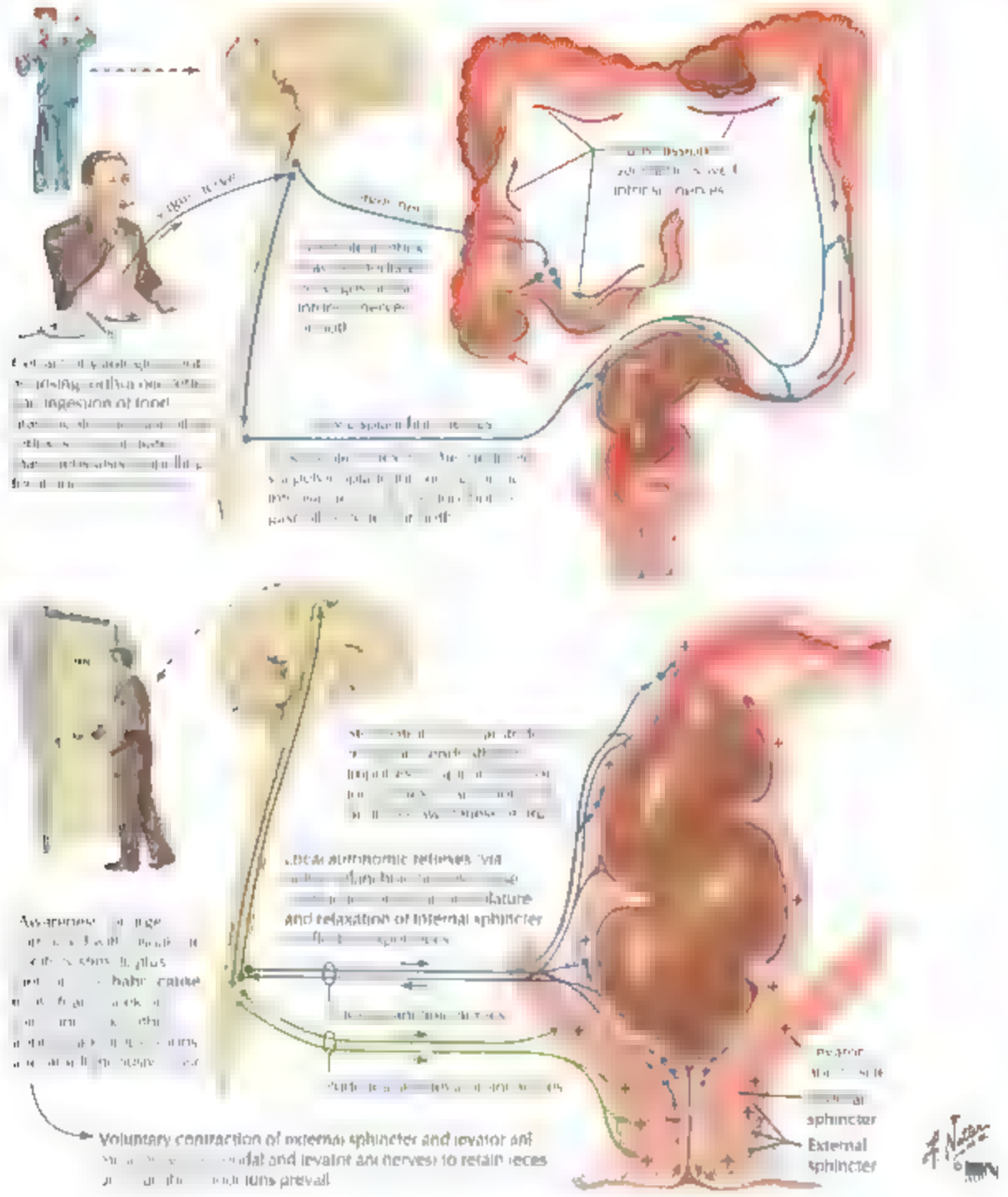


FIGURE 7.23 DEFECATION

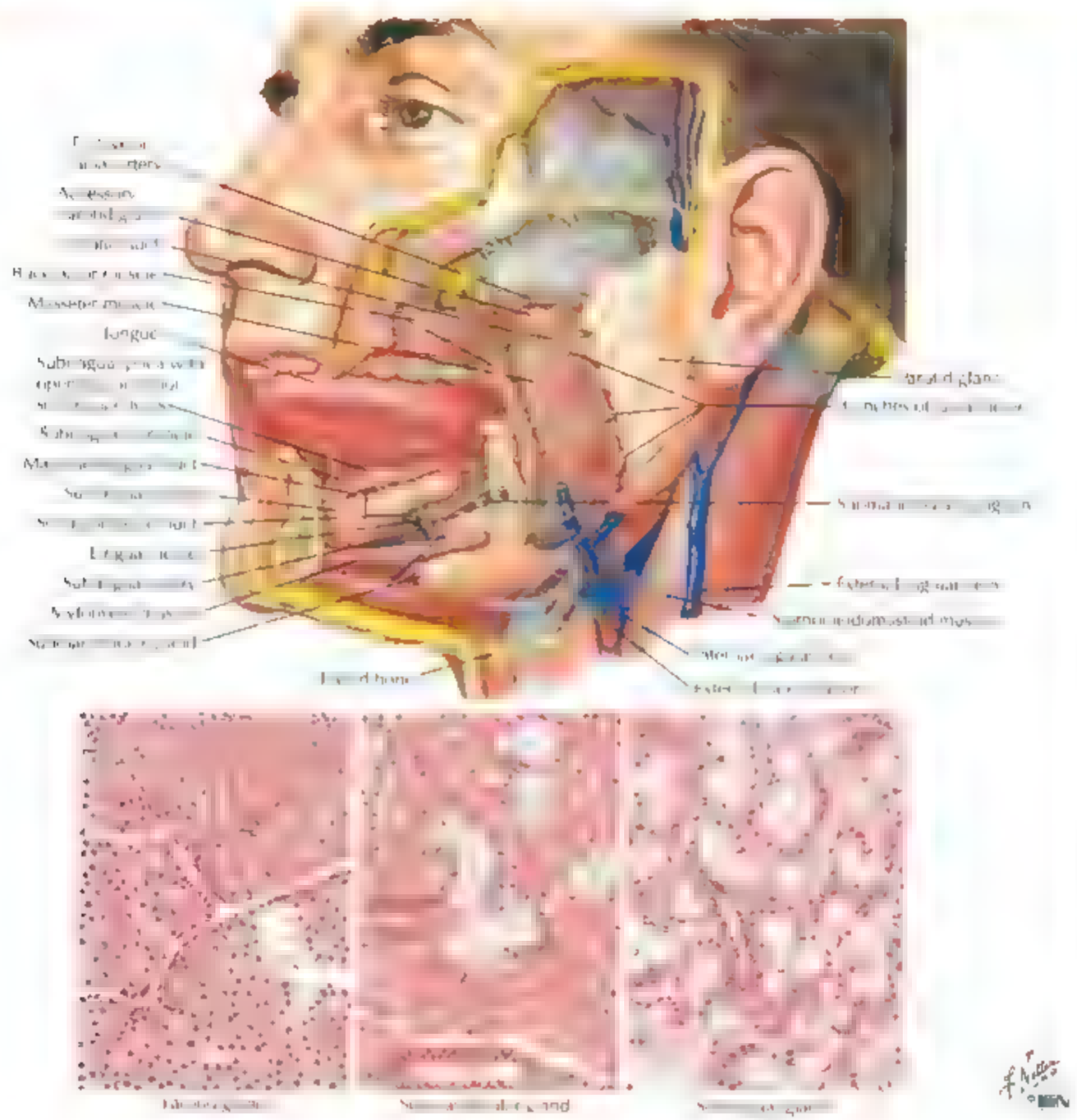


FIGURE 7.24 SALIVARY GLAND STRUCTURE

The salivary glands secrete saliva that keeps the oral cavity moist and aids in the digestion of food. Saliva is produced by serous acinar cells and mucous acinar cells. Serous acinar cells secrete a watery solution containing electrolytes and enzymes, including salivary amylase and lingual lipase. Mucous acinar cells secrete mucus, which is a viscous solution containing mucopolysaccharides and glycoproteins. The parotid gland is composed entirely of serous acinar cells. The submandibular gland contains both serous and mucous acinar cells. The sublingual gland is composed primarily of mucous acinar cells. Saliva is hypotonic relative to plasma.

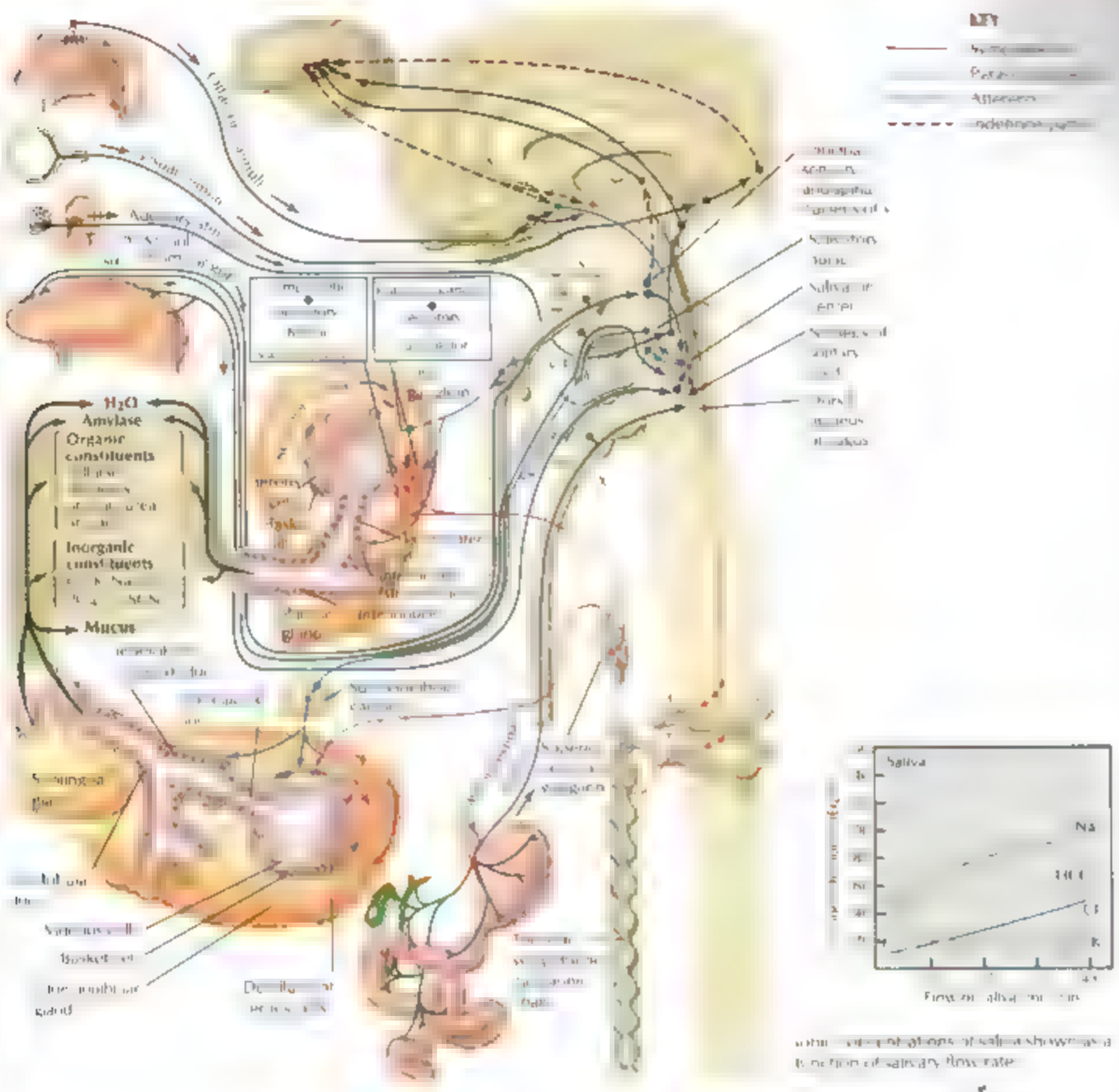


FIGURE 7.25 SALIVARY GLAND SECRETION

The salivary glands are under autonomic control. The glands receive both sympathetic and parasympathetic input. Unlike the glands of other systems, acinar cells in the salivary glands secrete both water and electrolytes. Ductal cells secrete bicarbonate and potassium ions and reabsorb sodium and chloride ions. The net result is secretion of saliva that is hypotonic to plasma. The composition of saliva changes as a function of salivary flow rate. At low flow rates, saliva is isotonic and has a high bicarbonate concentration. As the saliva makes its way through the salivary duct system, the ductal cells modify the composition such that saliva entering the mouth is hypotonic and has a low bicarbonate concentration.

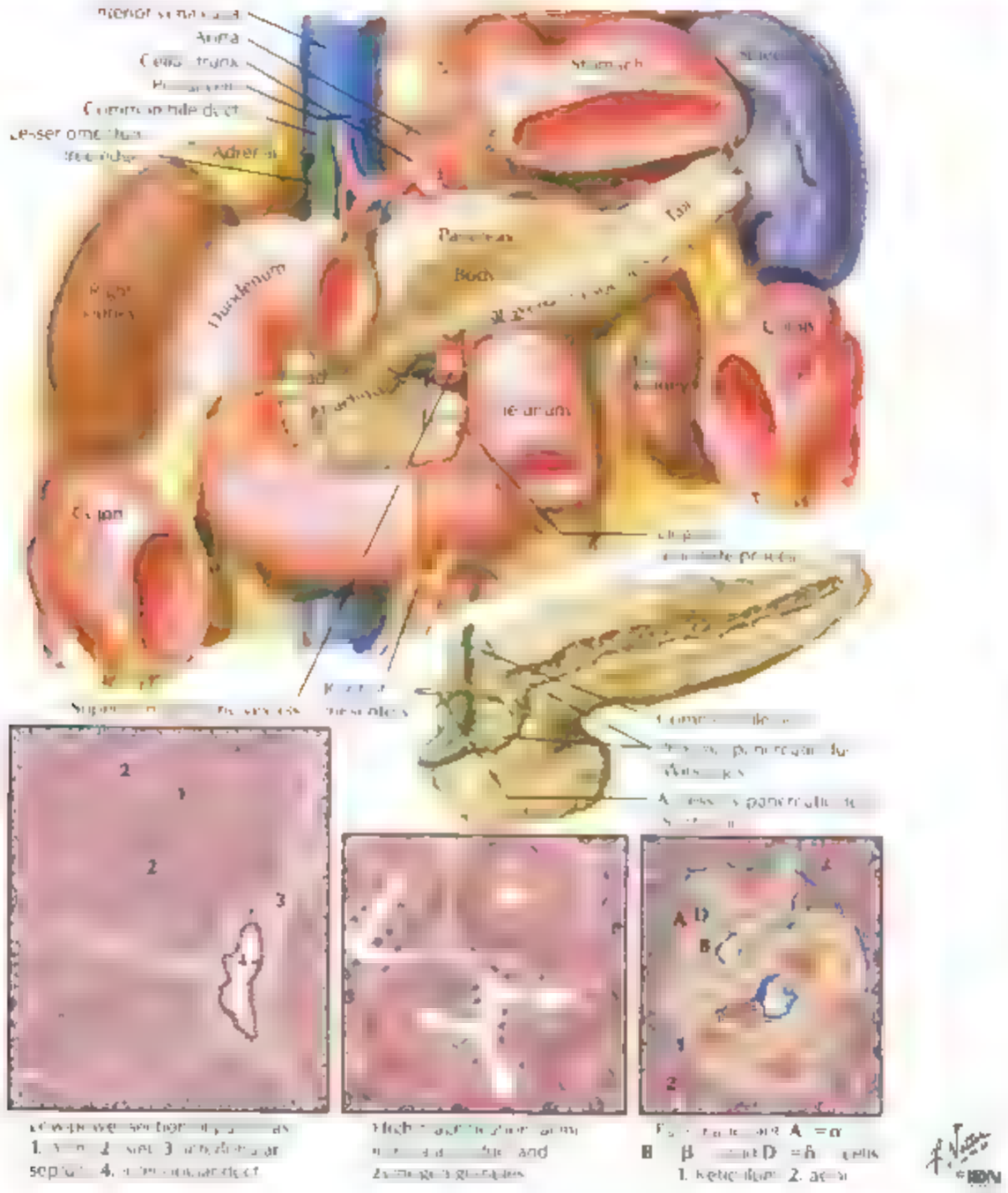


FIGURE 7.26 PANCREAS STRUCTURE

The pancreas has exocrine and endocrine components. The acinar cells of the exocrine pancreas secrete a number of enzymes that are necessary for digestion. Ductal cells secrete bicarbonate and also modify the ductal fluid with a high HCO$_3^-$ content. Bicarbonate helps neutralize the acid entering the duodenum from the stomach. The endocrine pancreas consists of islets of Langerhans. Within each islet, the A or α cells are located in the periphery of the islet, secrete glucagon, the B or β cells are located centrally in the islet, secrete insulin, and the D or δ cells are dispersed throughout the islet, secrete somatostatin.

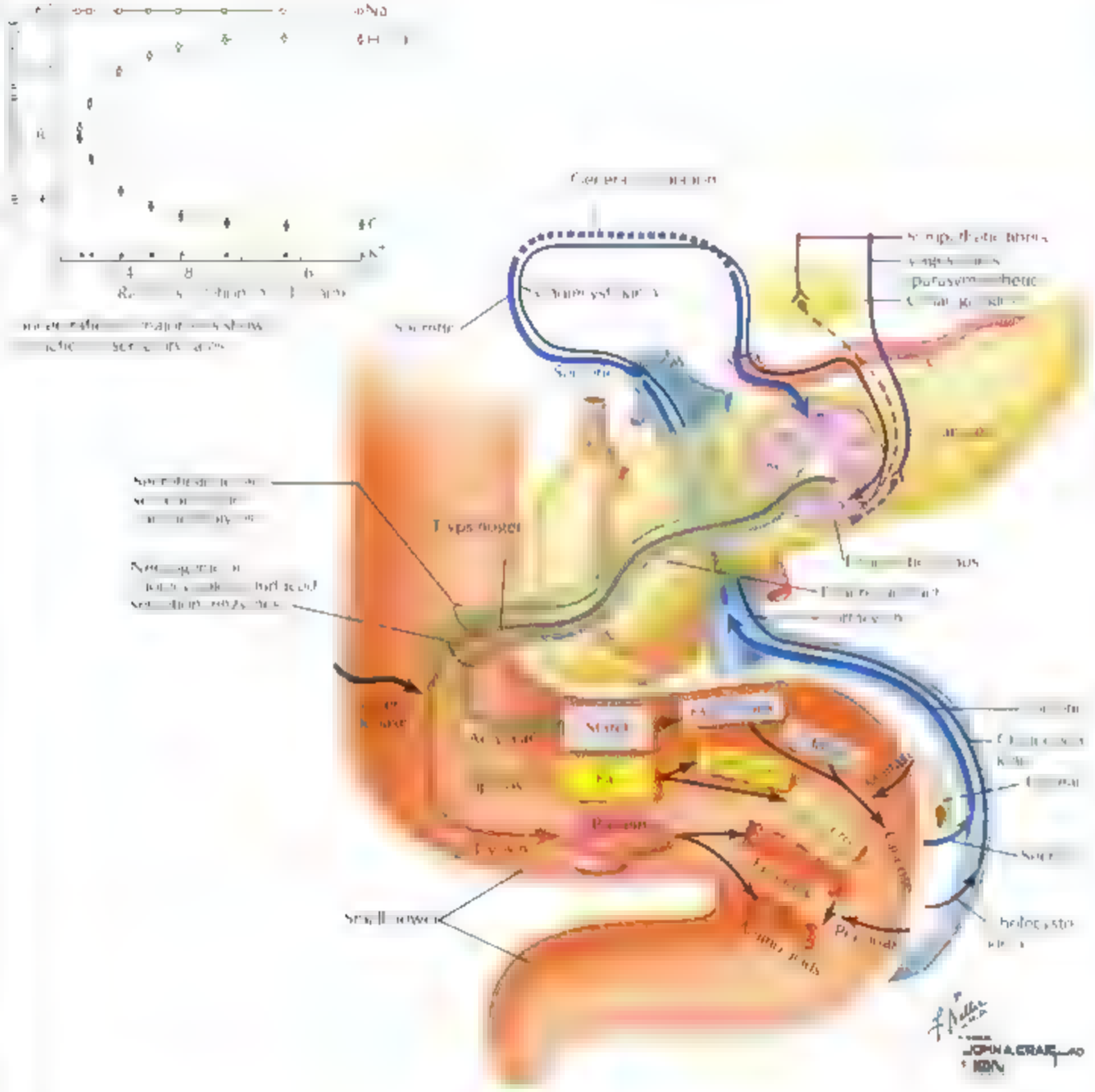


FIGURE 7.27 PANCREAS SECRETION

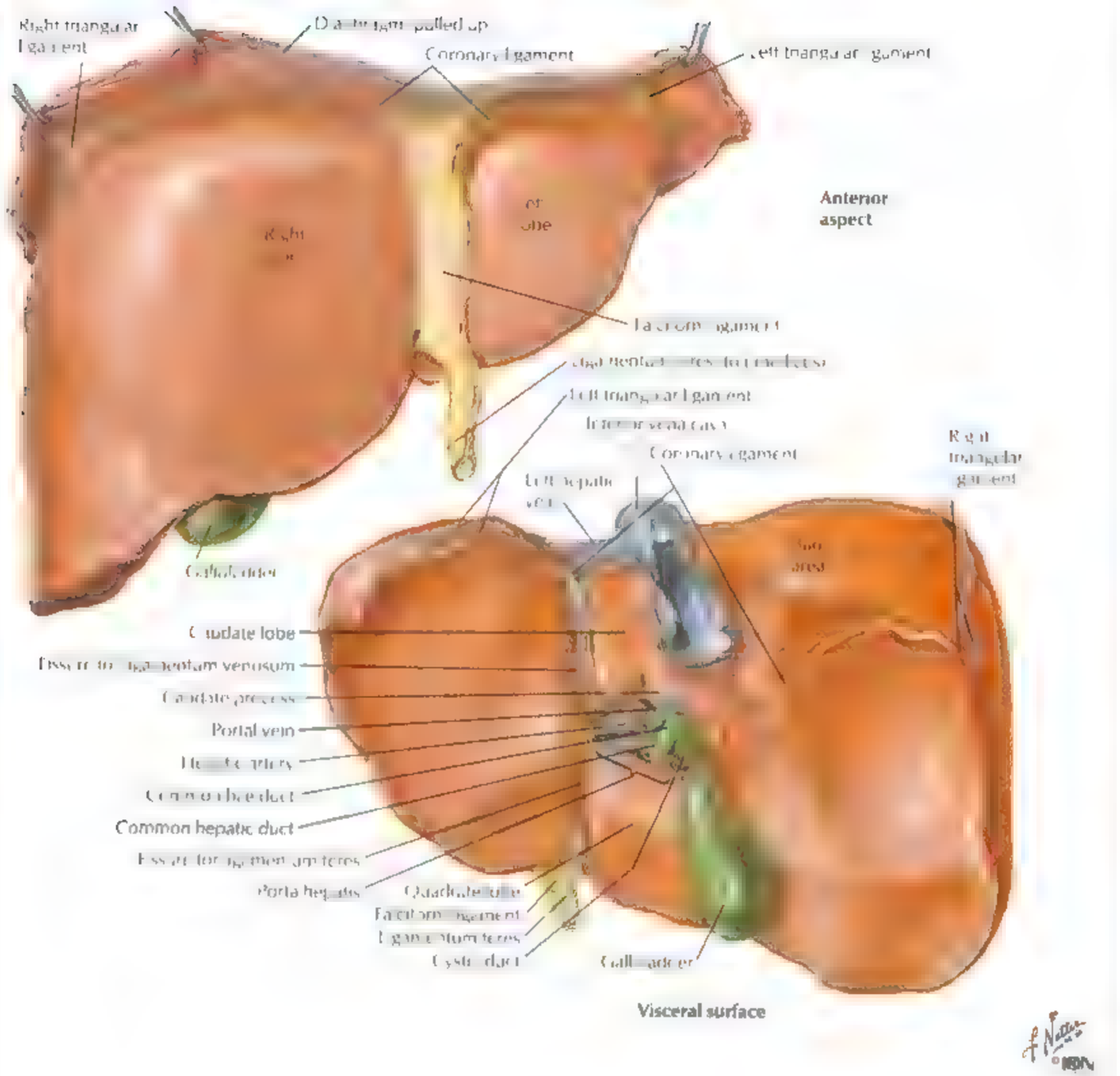


FIGURE 7.28 LIVER STRUCTURE

The liver is the largest gland in the body and consists of four anatomical lobes (right, left, quadrate, and caudate). Various ligaments attach the liver to the overlying diaphragm (coronary ligaments) and anterior abdominal wall (falciform ligament). Functionally, the liver has two lobes, right and left, and each lobe receives arterial blood from the hepatic artery and portal venous blood from the abdominal GI tract. Each lobe also possesses its own venous and biliary drainage

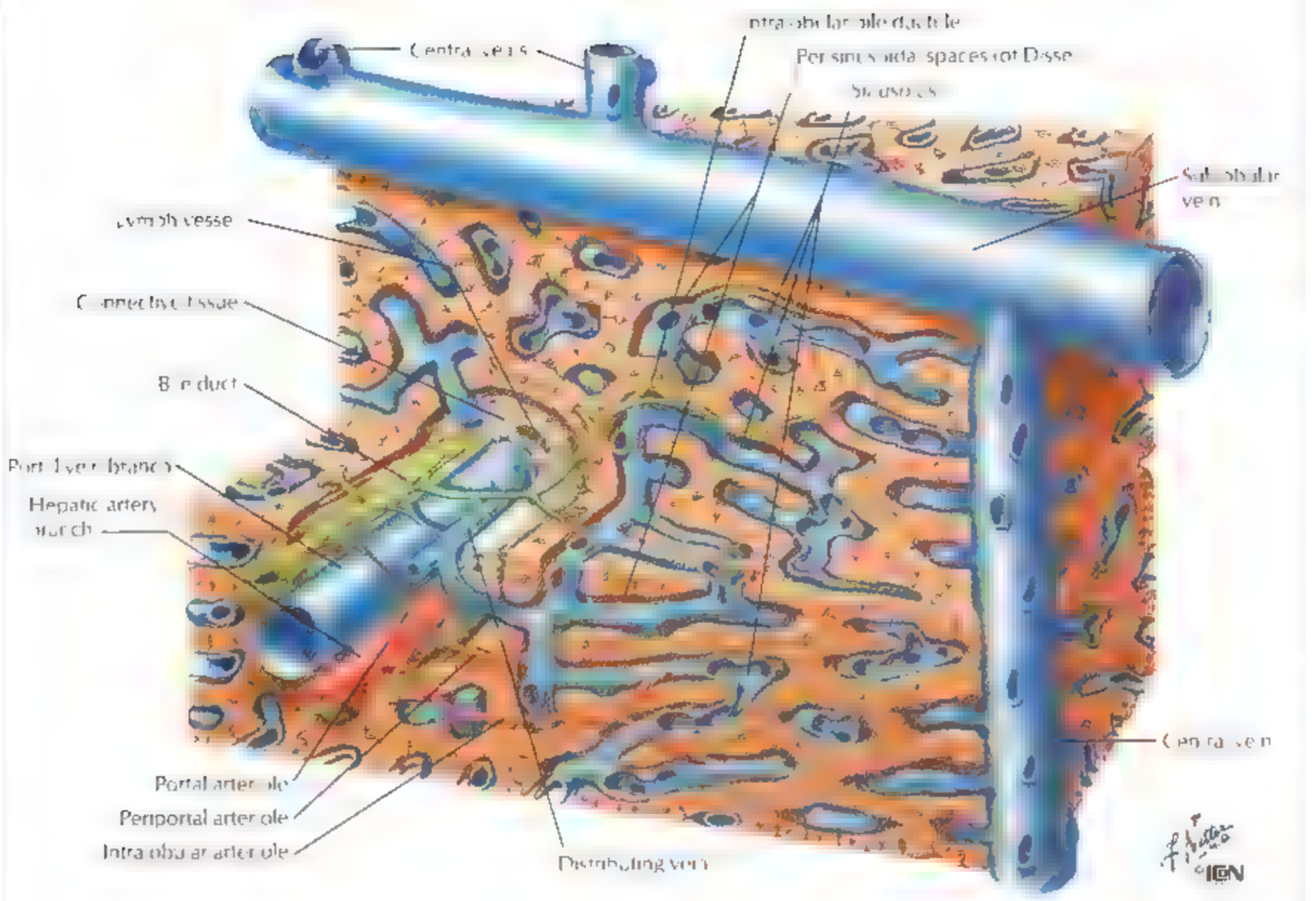


FIGURE 7.29 LIVER ULTRASTRUCTURE

The liver cells (hepatocytes) receive blood from the portal circulation (75% arrives from the hepatic artery, 25% from the portal vein). Hepatocytes are arranged in plates of cells that are separated from each other by hepatic sinusoids. The blood flows from the portal vein and hepatic arteriole branches through the sinusoids to the central vein. From the central vein, blood flows into the hepatic veins and inferior vena cava. The sinusoids are lined by a discontinuous endothelium that allows free movement of proteins from the blood to the hepatocytes as well as from the hepatocytes to the blood. The sinusoids also contain phagocytic cells (kupffer cells) that clear damaged red blood cells and other debris (e.g., antigens, not shown). Bile is produced by the hepatocytes and drains into intralobular bile canaliculi and then larger bile ducts (right and left). The bile ducts connect with the hepatic, cystic, and common bile ducts, which transport bile to the gallbladder, where it is stored and concentrated.

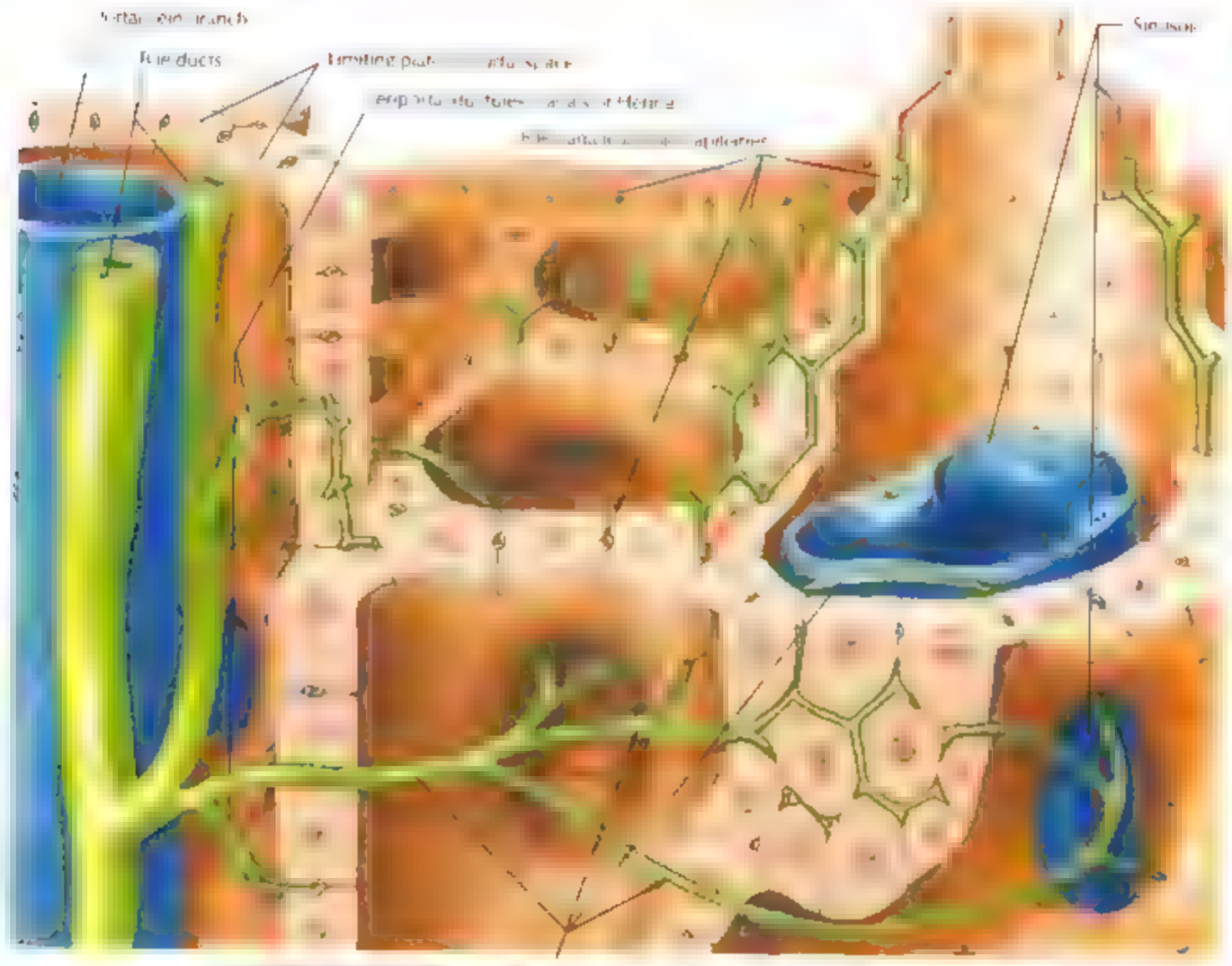


FIGURE 7.30 INTRAHEPATIC BILIARY SYSTEM

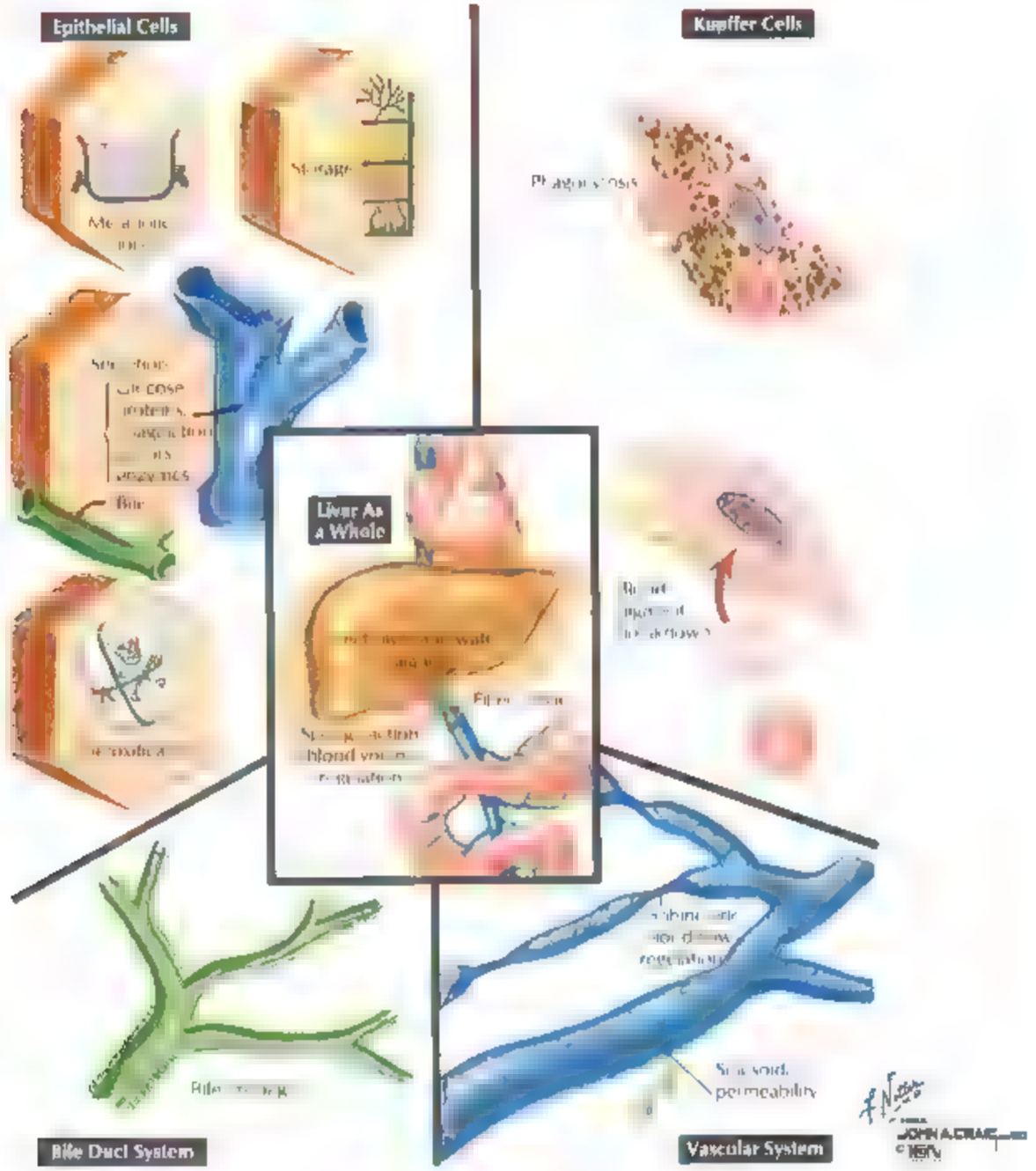


FIGURE 7-31 OVERVIEW OF LIVER FUNCTION

The liver serves a number of important functions, including storage of important nutrients and energy sources (e.g., glycogen, iron, and vitamins), production and modification of proteins (e.g., albumin, clotting factors, cholesterol, lipids, and bile acids), production of plasma proteins that help establish osmotic forces and drugs, the excretion of substances (e.g., bilirubin) and the production of bile acids. The hepatic cells phagocytose foreign materials that cross the wall of the GI tract and enter the portal circulation. Cells of the mononuclear phagocytic system (MPS), also known as the Kupffer cells, throughout the body phagocytose damaged red blood cells, follow their destruction by hemoglobin degradation, and excrete the liver in the bile (see Figure 7-...).

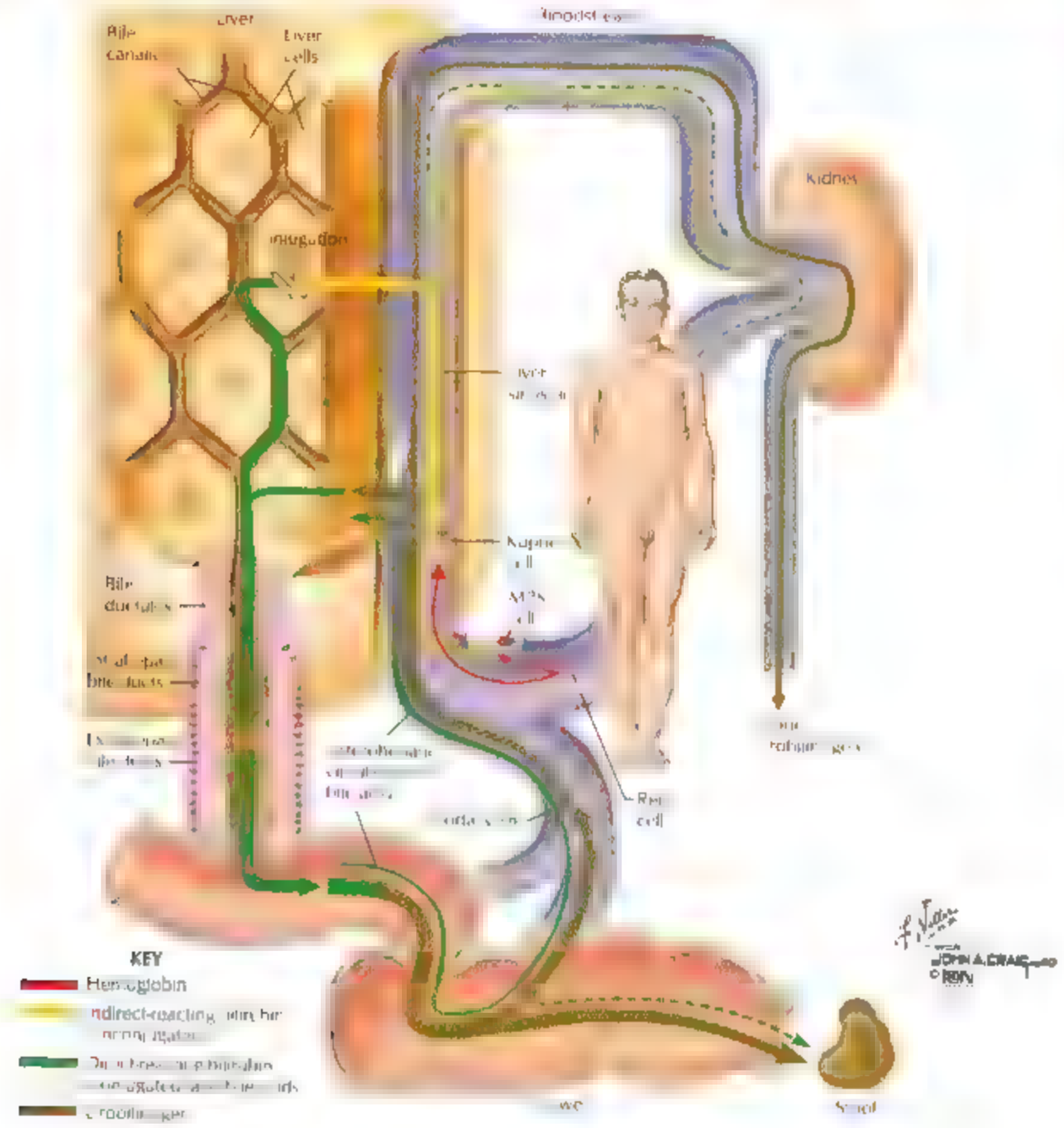
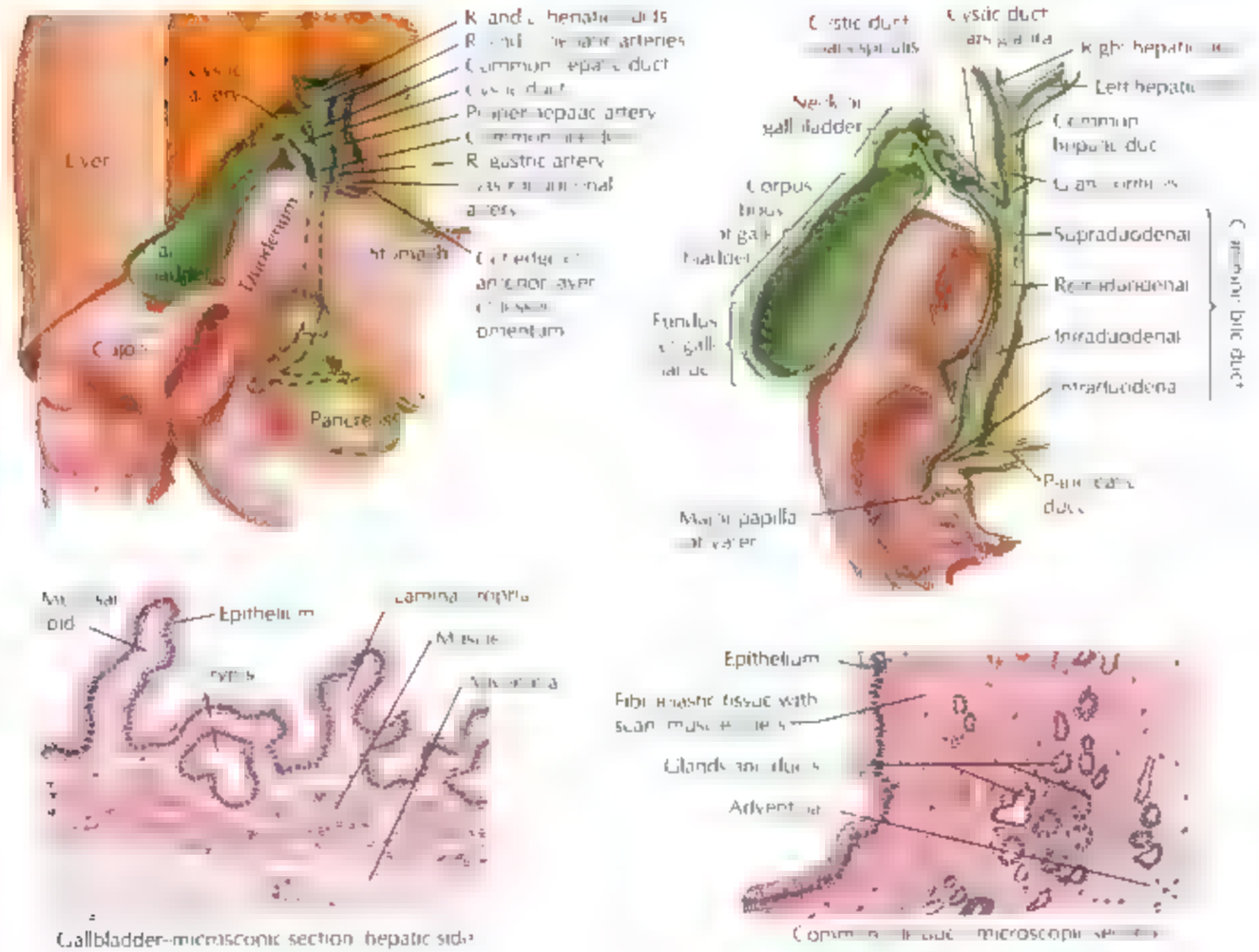


FIGURE 7.32 BILIRUBIN PRODUCTION AND EXCRETION

Cells of the mononuclear phagocytic system (MPS), both in the liver (Kupffer cells) and throughout the body, phagocytose damaged red blood cells. Bilirubin, a degradation product of hemoglobin, is released by these cells (unconjugated bilirubin). The liver hepatocytes take up this bilirubin, conjugate it with glucuronic acid (conjugated bilirubin), and excrete it in the bile. In the intestine the bilirubin is converted to urobilinogen by bacterial action. Some of this urobilinogen is absorbed and returned to the liver, with the rest excreted in the bile. Some of the urobilinogen is also excreted by the kidneys. The bile also contains bile acids, which aid in the digestion of lipids by their ability to emulsify fats and form mixed micelles with the lipid molecules (see Figure 7.37). Bile acids are reabsorbed by the terminal ileum. Typically, 95% of the bile acids are recirculated in this manner (enterohepatic circulation). The bile acids lost in the feces each day are replaced by hepatic synthesis.



Gallbladder–microscopic section, hepatic side

Common bile duct, microscopic section

FIGURE 7.33 GALLBLADDER STRUCTURE AND FUNCTION

The gallbladder is a small, pear-shaped organ attached to the inferior surface of the liver. It serves to store and concentrate the bile synthesized by the liver. It holds about 20 to 50 mL of bile. Vagal stimulation and the hormone cholecystokinin released by enteroendocrine cells in the duodenum, in response to the presence of fat, cause the gallbladder to contract and transport bile down the cystic duct and the common bile duct where it empties into the second descending portion of the duodenum. The gallbladder mucosa is specialized for electrolyte and water absorption, which allows the gallbladder to concentrate the bile.

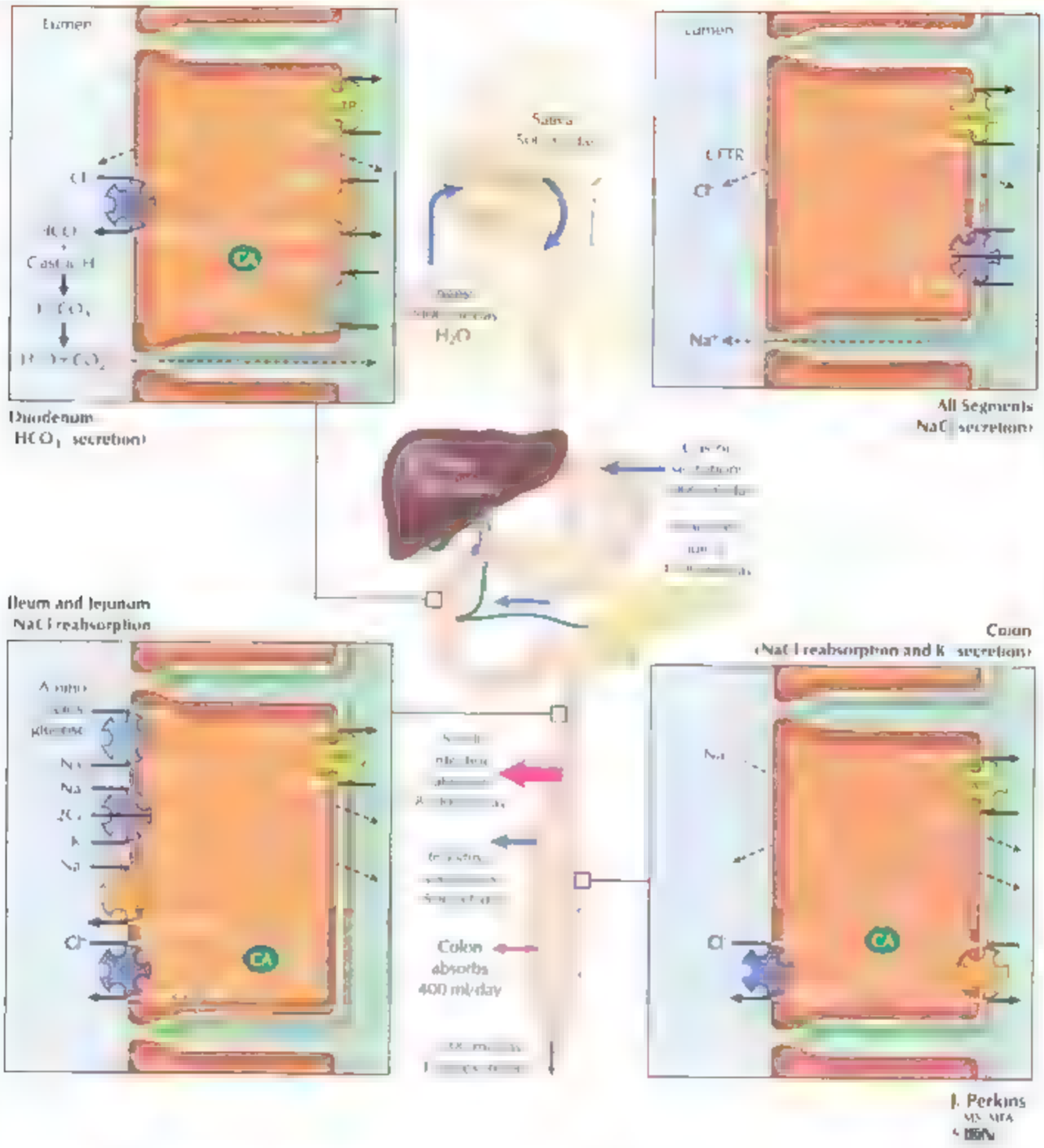


FIGURE 7.34 GI TRACT FLUID AND ELECTROLYTE TRANSPORT

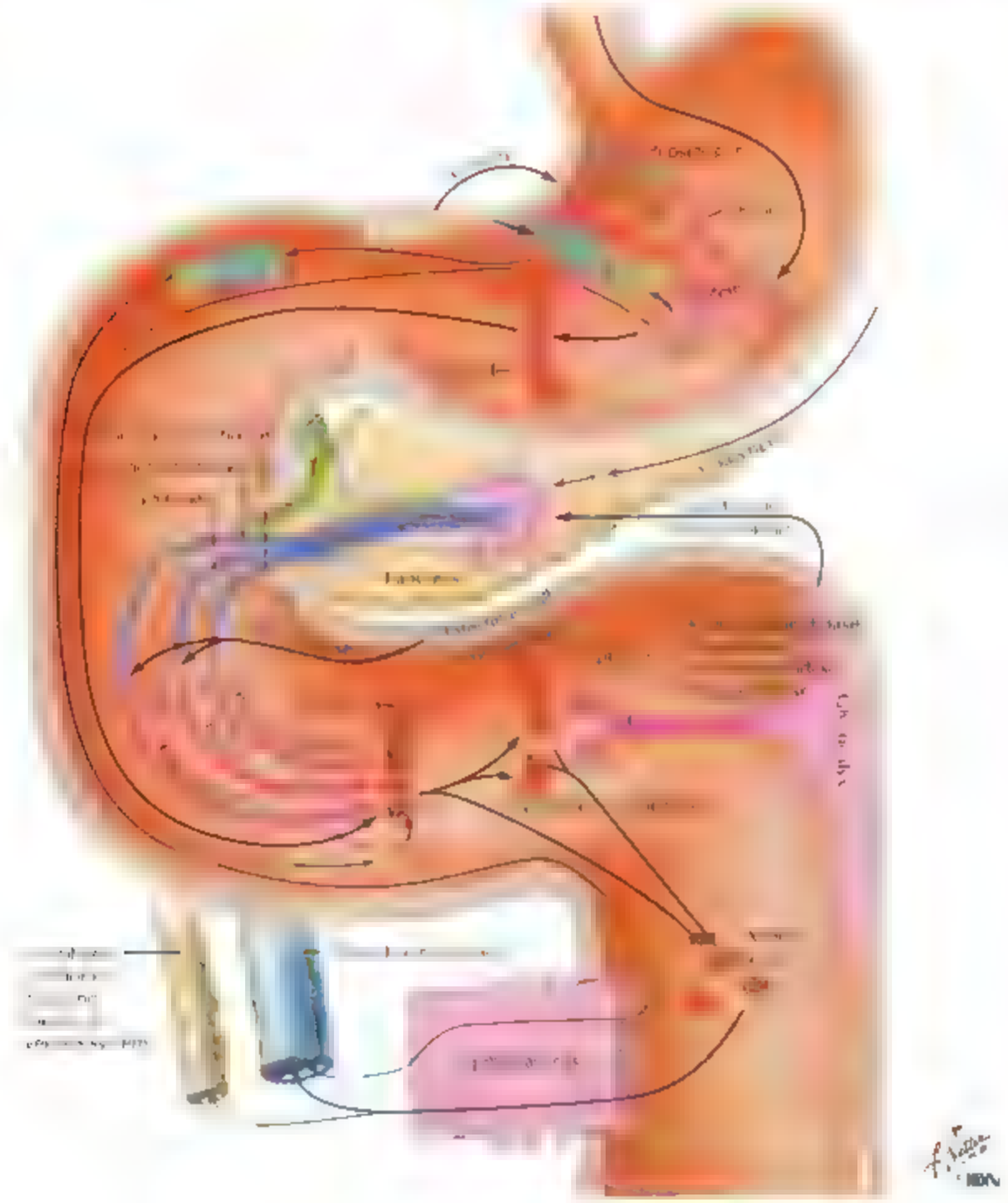


FIGURE 7.35 DIGESTION OF PROTEIN

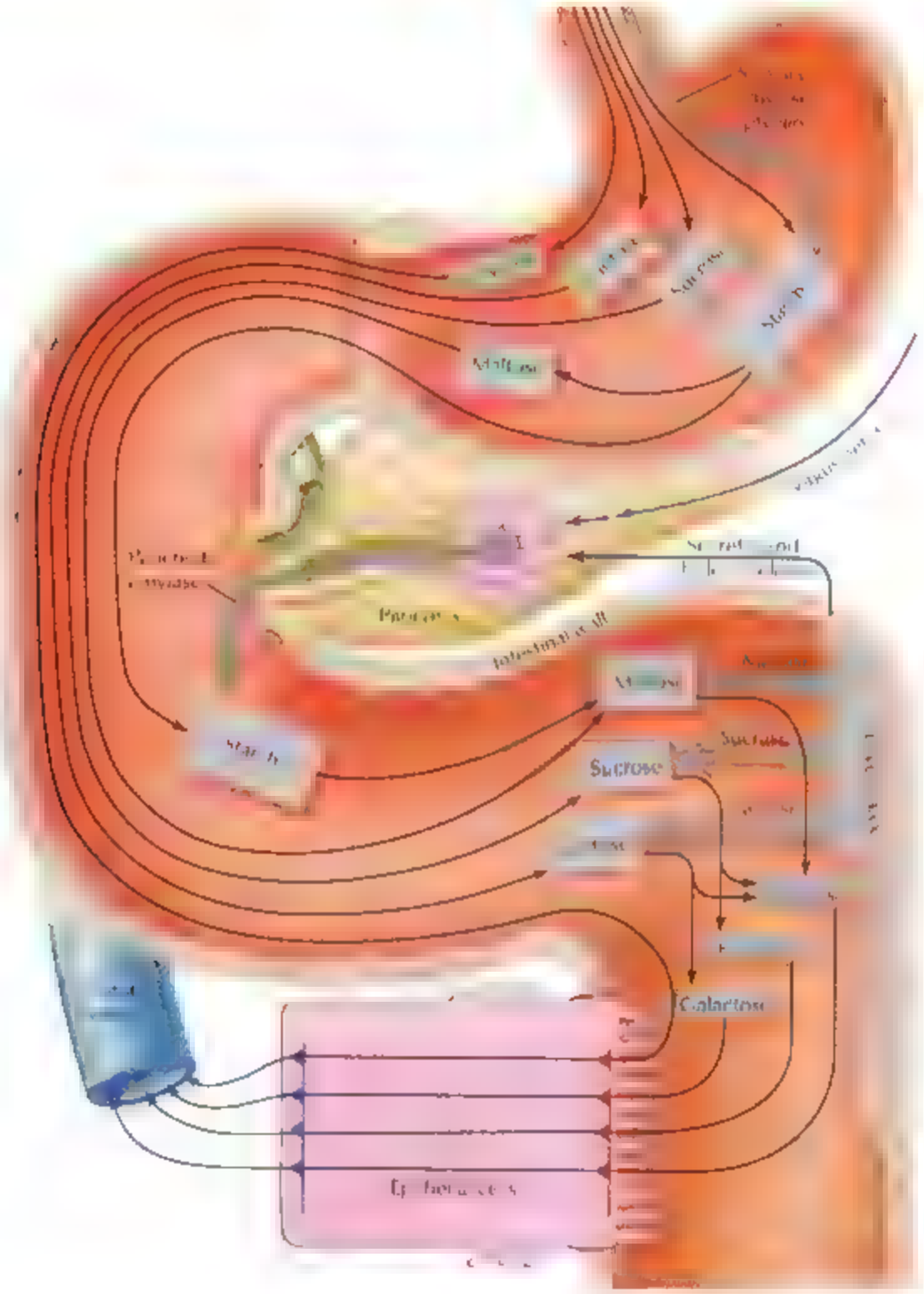


FIGURE 7.36 DIGESTION OF CARBOHYDRATES

Digestion of carbohydrates and [illegible] through the mouth and stomach through the action of salivary [illegible] and pancreatic amylase and [illegible] associated with the brush border of the intestinal cell [illegible] process yielding monosaccharides. The glucose, [illegible] sucrase, and [illegible] shown in figure 4. The monosaccharides are absorbed by the intestinal epithelial cells and [illegible] Na+ ions (figure 4).

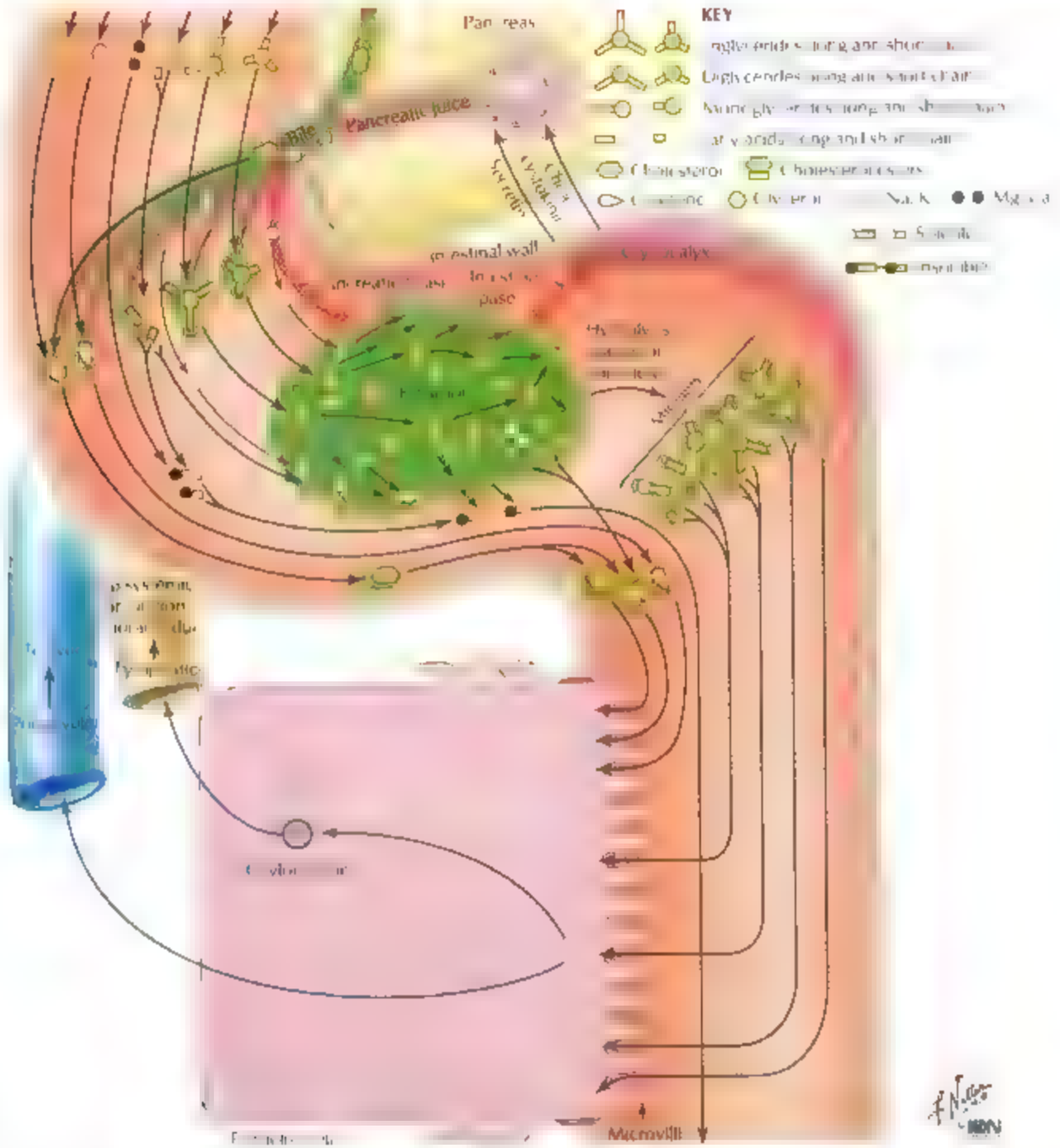
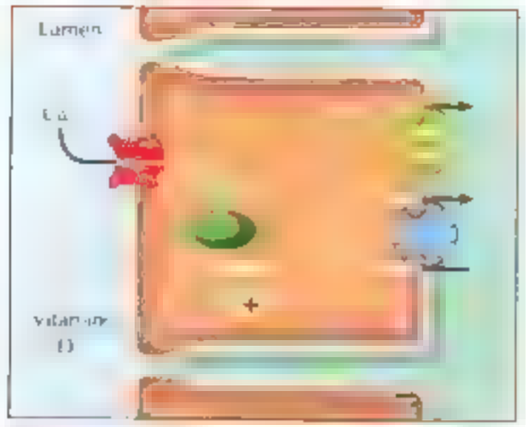
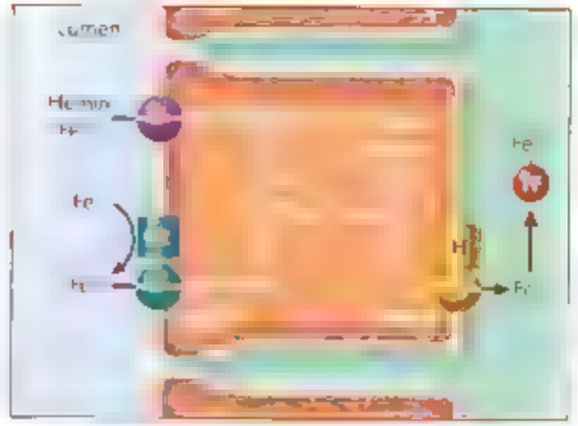
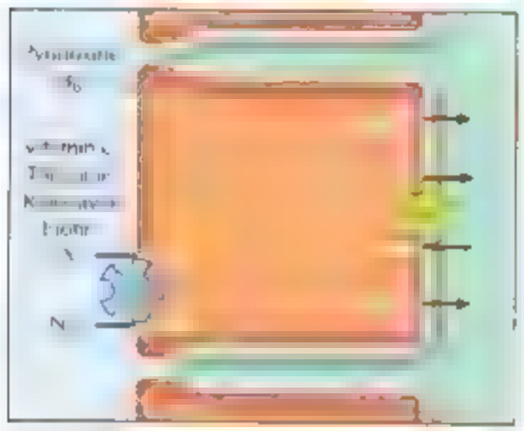


FIGURE 7-37 DIGESTION OF FAT

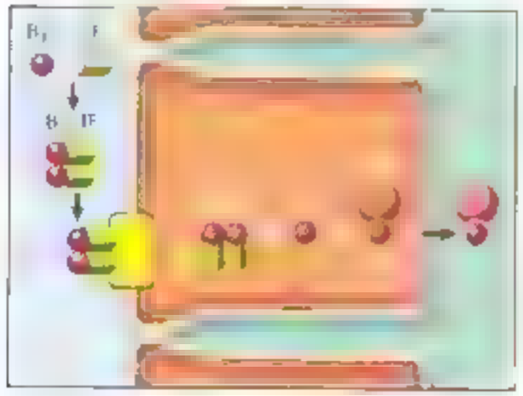
Although some digestion of fat occurs in the stomach, most digestion and absorption occurs in the small intestine. The digestion of fat is associated with the physiology of the epithelial cells of the intestinal wall. The fat cells of the digestive tract play a role in this process but they are not essential. Fatty acids and monoglycerides combine with bile salts to form micelles, which pass through the unstirred layer of mucus and enter the epithelial cells of the villi. Here they are resynthesized into triglycerides and phospholipids. These combine with cholesterol and cholesterol esters and are coated with protein to form chylomicrons. These are then extruded from the cell by exocytosis and enter the lacteals. The lacteals empty into the lymphatic system, which eventually empties into the venous circulation. Micelles also contain fat-soluble vitamins (A, D, E, and K), which are absorbed along with the fat. Bile salts are then recycled by active transport in the terminal ileum.

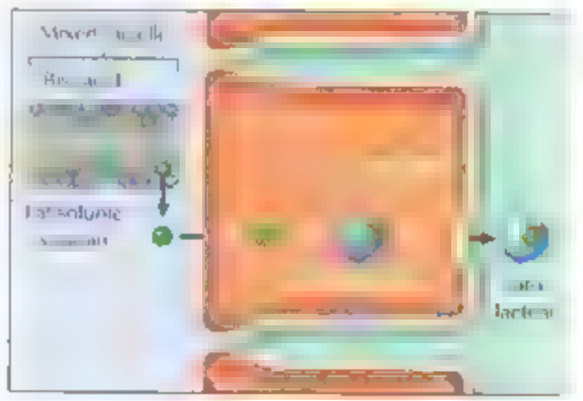






Element	Site of Absorption	Mechanism
Ca	[illegible]	Active
Fe	[illegible]	[illegible]
Water-Soluble Vitamins		
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Fat-Soluble Vitamins		
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]





J. Perkins
[illegible]

FIGURE 7.38 ABSORPTION OF ESSENTIAL VITAMINS AND ELEMENTS

[illegible]

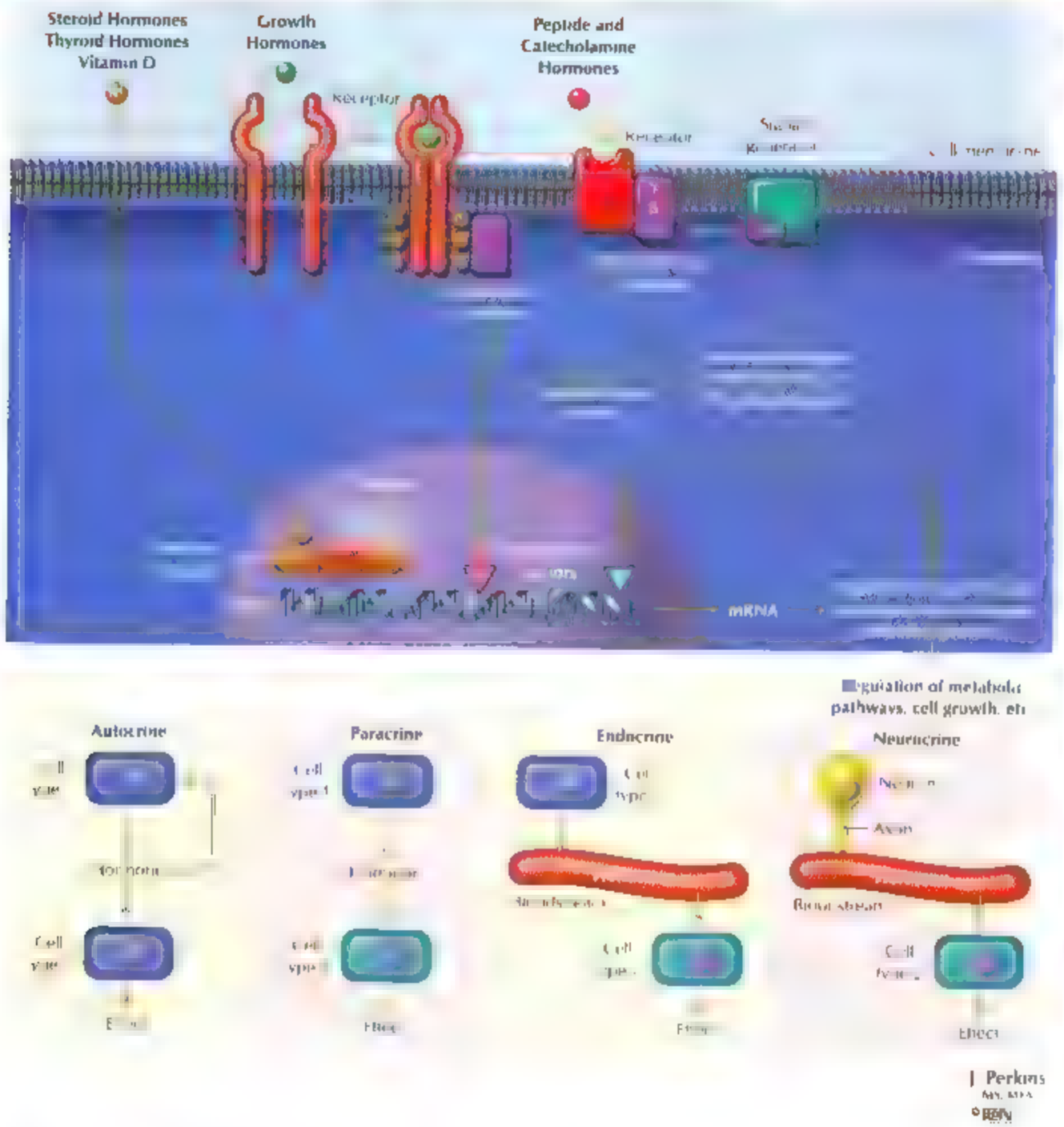


FIGURE 8.1 OVERVIEW OF HORMONE ACTION

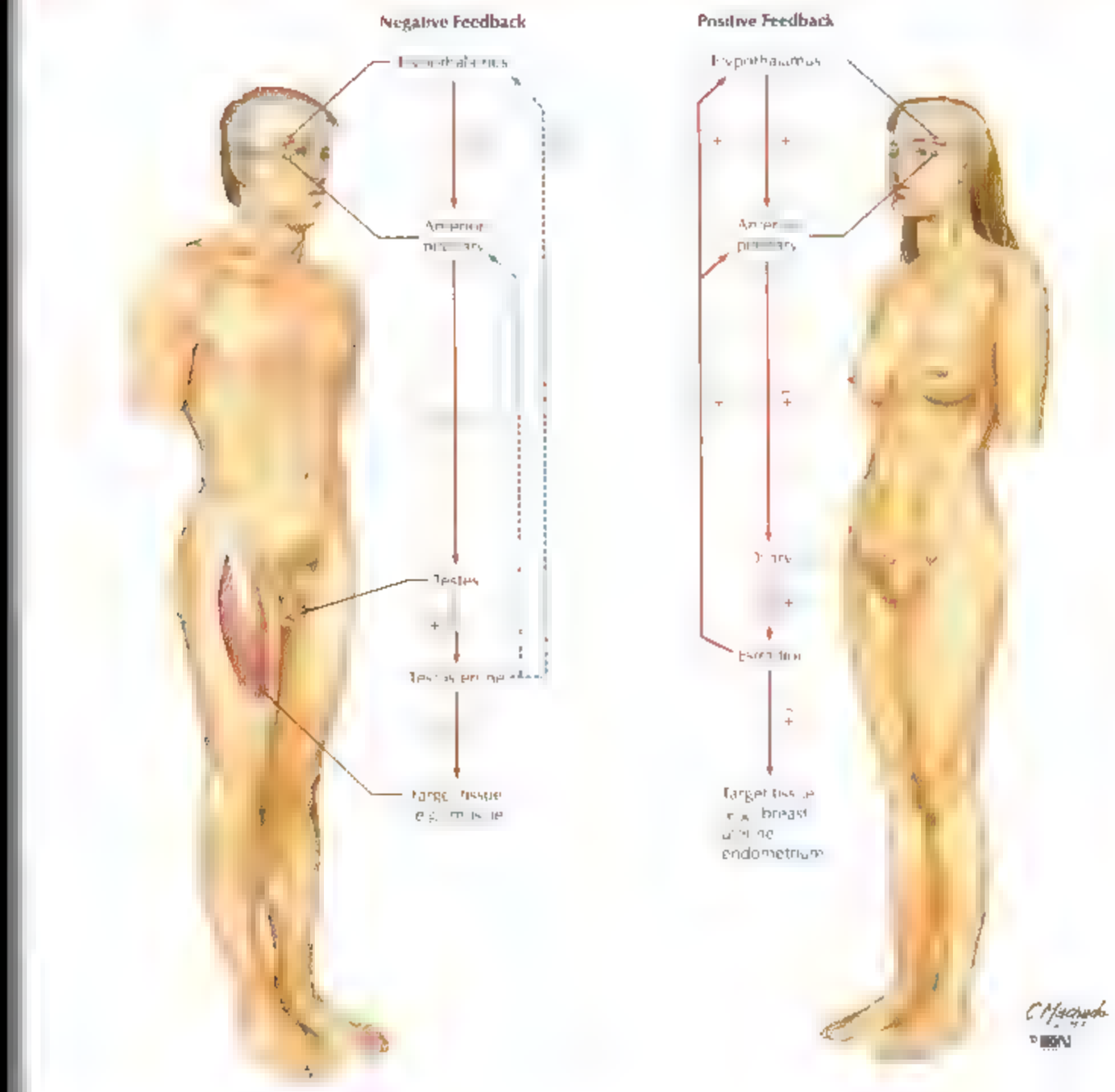


FIGURE 8.2 FEEDBACK REGULATION

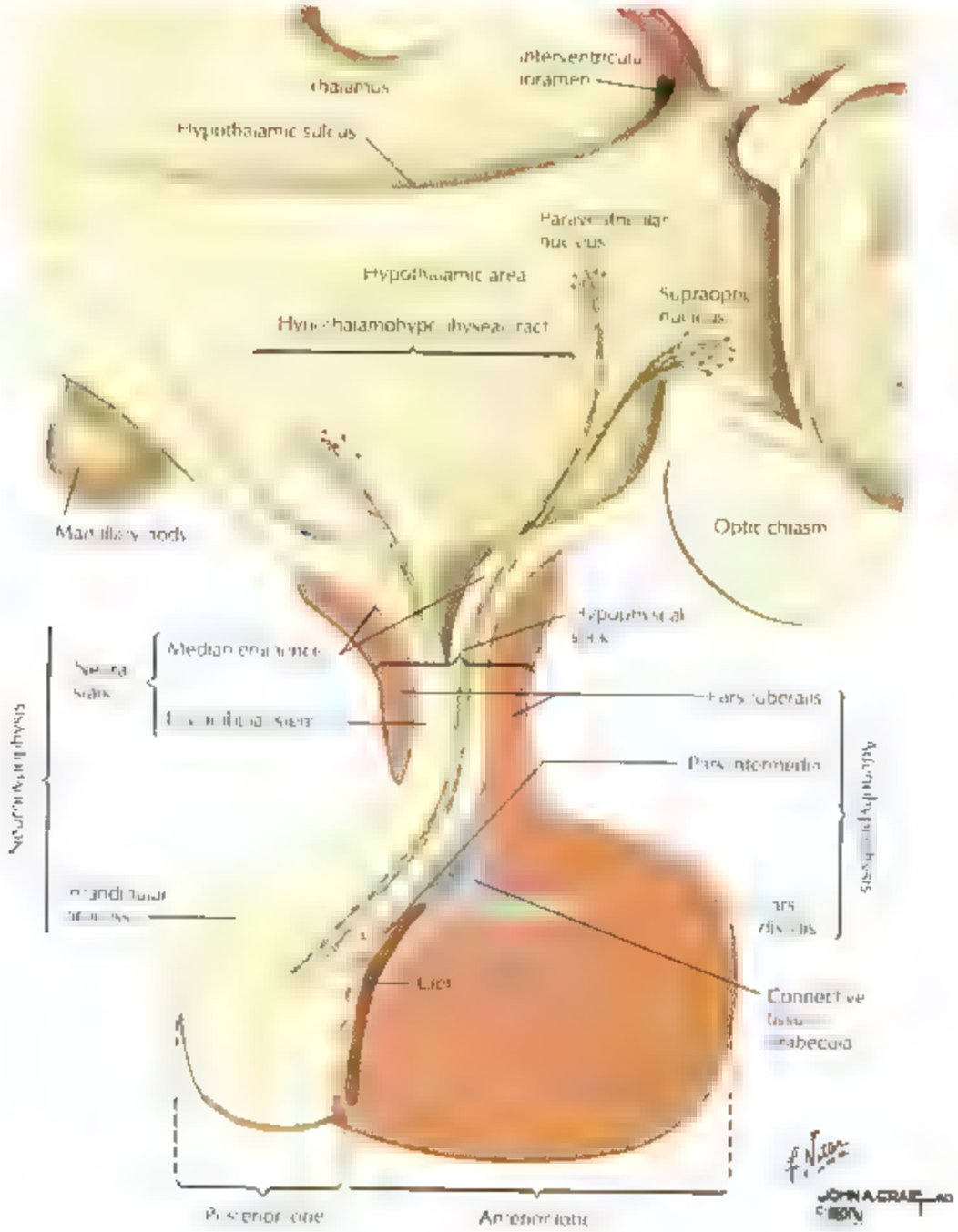


FIGURE 8.3 STRUCTURE OF HYPOTHALAMUS AND PITUITARY

The neurohypophysis and pituitary stalk form as a downgrowth of the diencephalon of the brain. The adenohypophysis develops from Rathke's pouch, a diverticulum in the oropharynx. The intermediate lobe is not well developed in humans. Neuroendocrine cells in the hypothalamus send axons into the posterior pituitary and to the region of the median eminence. Hormones are released from these axons into the blood perfusing the pituitary or into the hypothalamohypophyseal portal system (see figure 6.4) in the region of the median eminence.

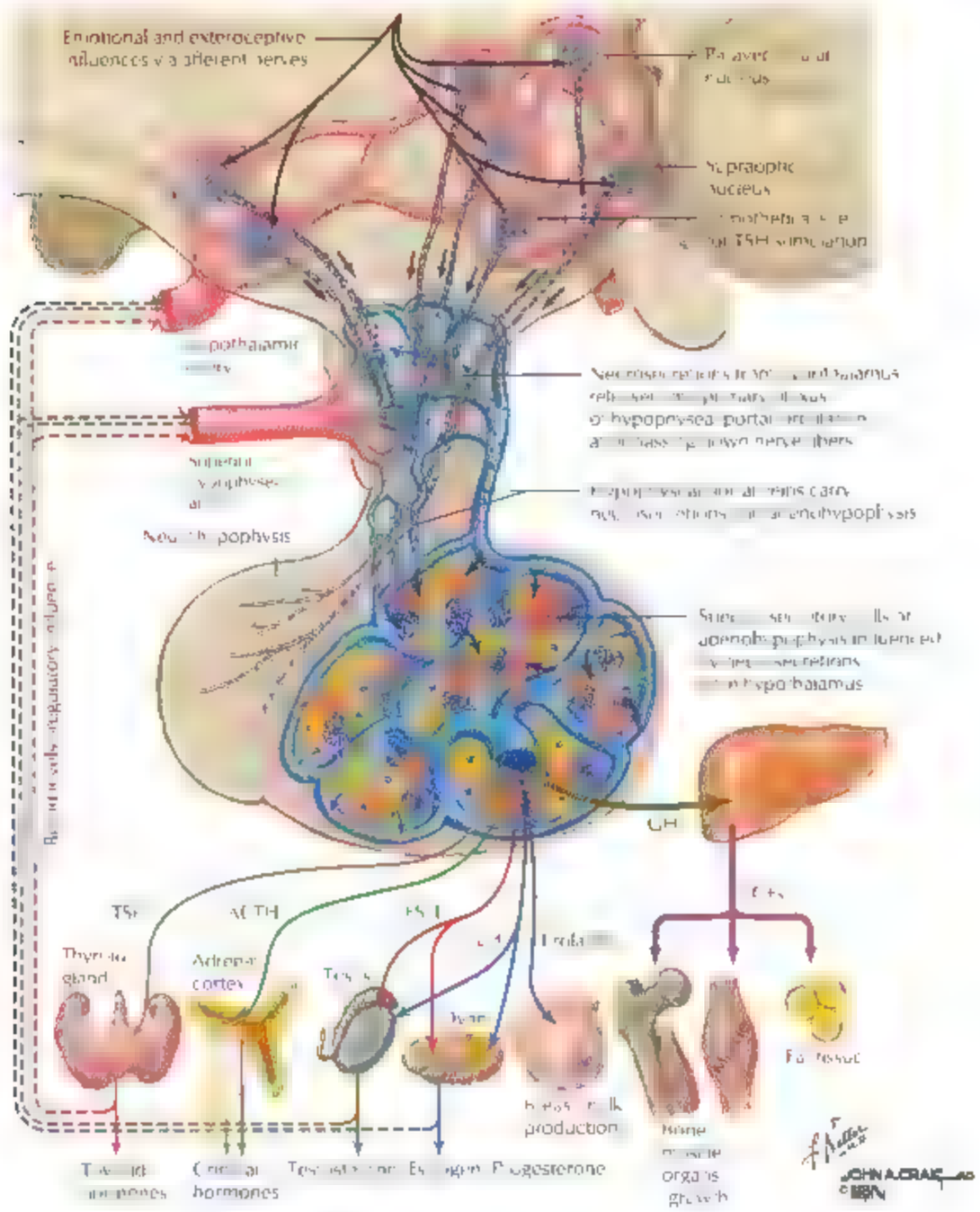


FIGURE 8.4 OVERVIEW OF ANTERIOR PITUITARY FUNCTION

Hypothalamic neurosecretory cells release hormones into the hypophyseal portal system that stimulate or inhibit the secretory cells of the anterior pituitary. Certain hypothalamic releasing and inhibiting hormones affect cells of the anterior pituitary that release hormones with hormonal actions. Target tissues for these hormones secreted by the anterior pituitary gland feed back on both the cells of the hypothalamus and anterior pituitary to regulate the secretion of trophic hormones or release of hormones.

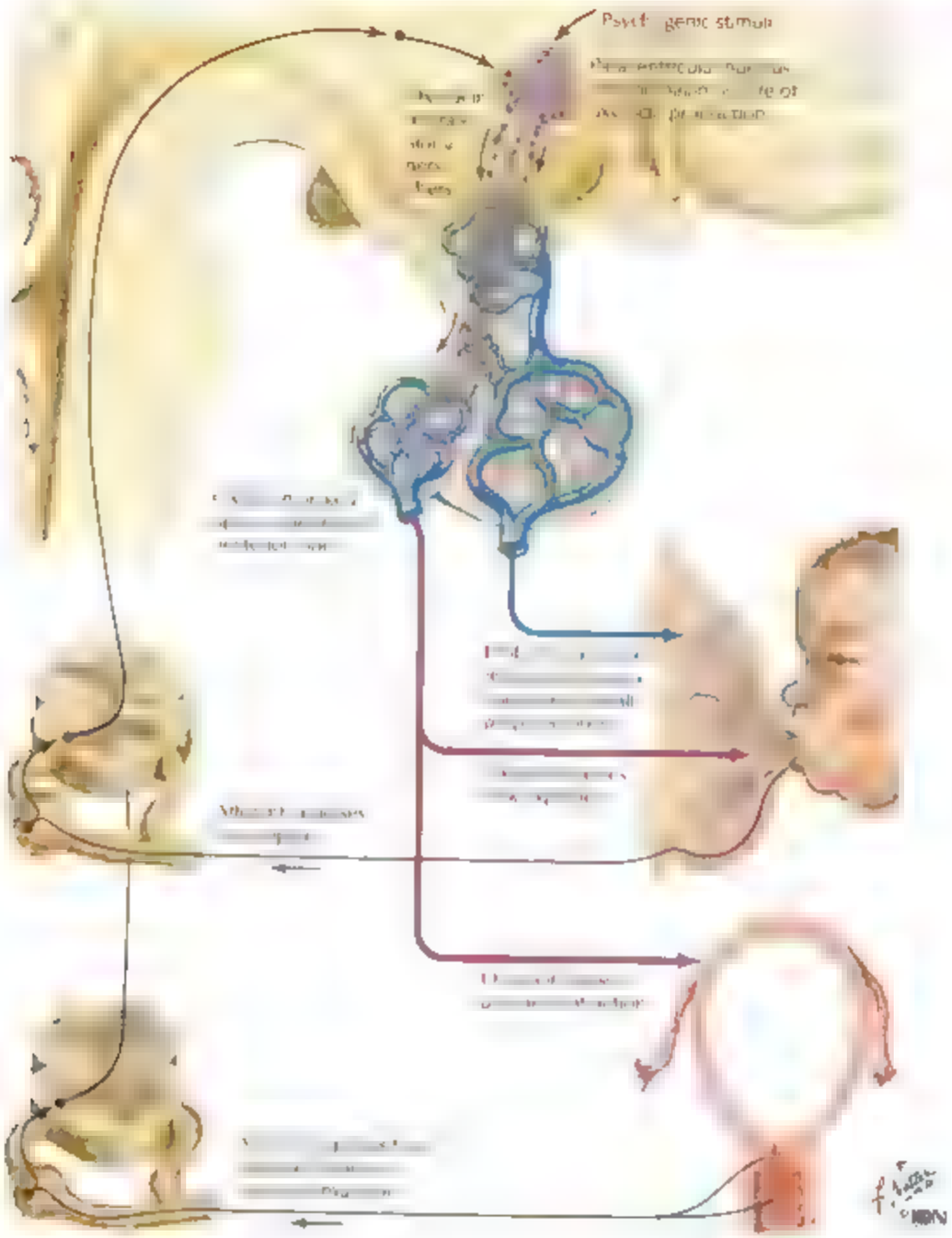


FIGURE 8.5 POSTERIOR PITUITARY FUNCTION (OXYTOCIN)

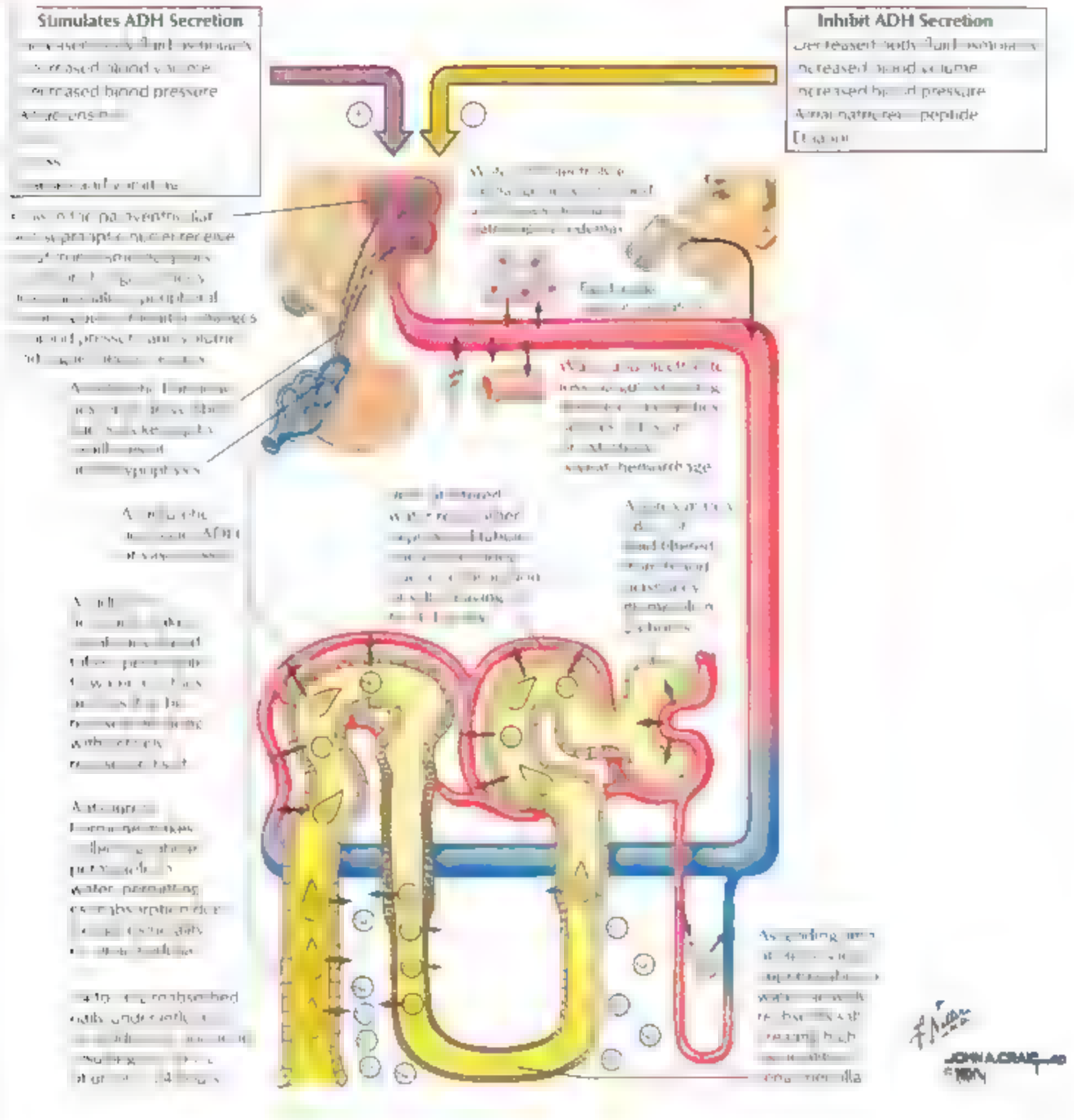


FIGURE 8.6 POSTERIOR PITUITARY FUNCTION (ADH)

ADH = antidiuretic hormone. ADH or vasopressin is released in response to changes in water balance. Changes in osmolarity and blood volume or pressure are the primary physiologic regulators of ADH secretion (see also Figure 8.5). When ADH levels are elevated, a small volume of concentrated urine is excreted. When ADH levels are low, a large volume of dilute urine is excreted.

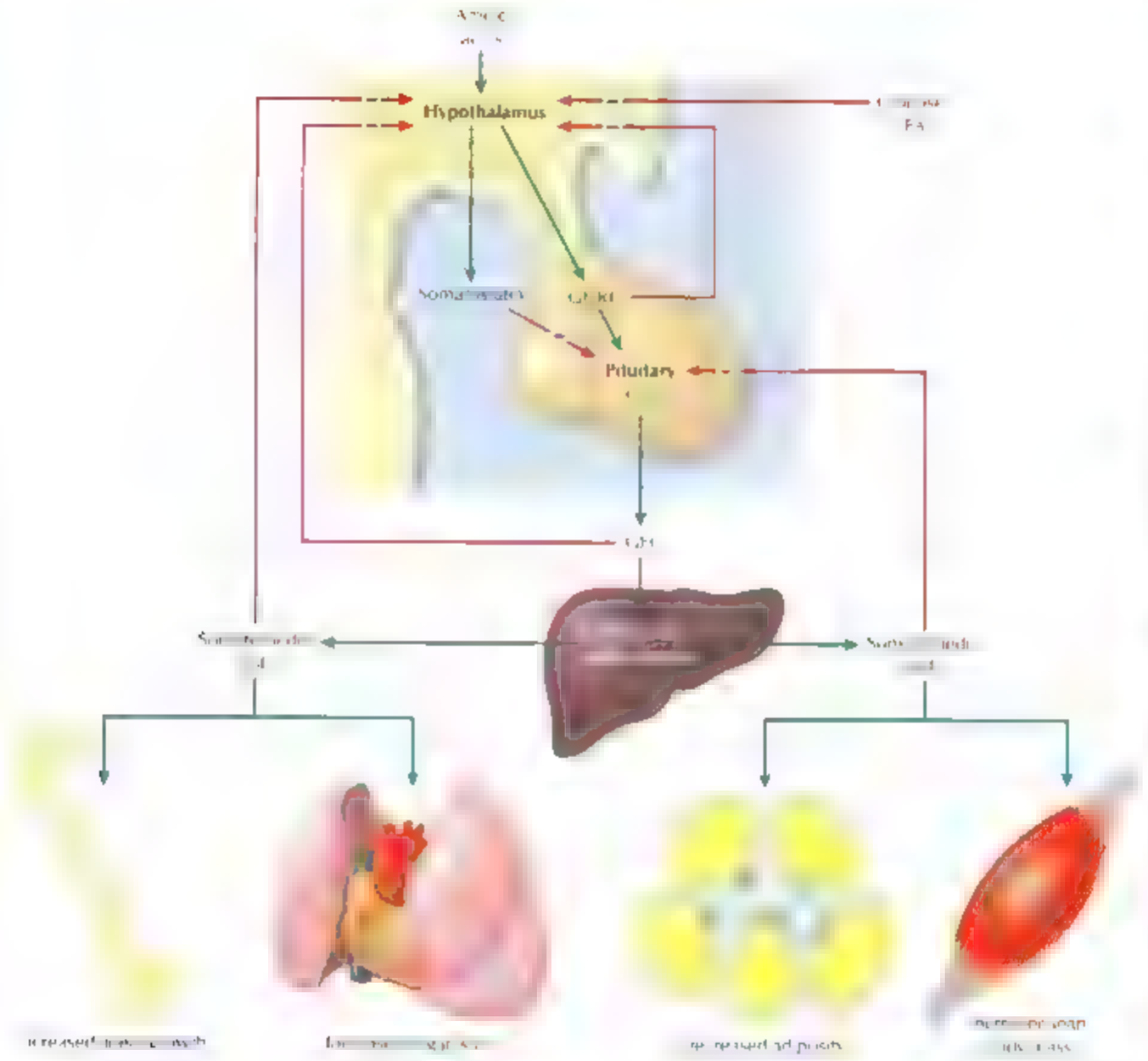


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FIGURE 8.7 GROWTH HORMONE

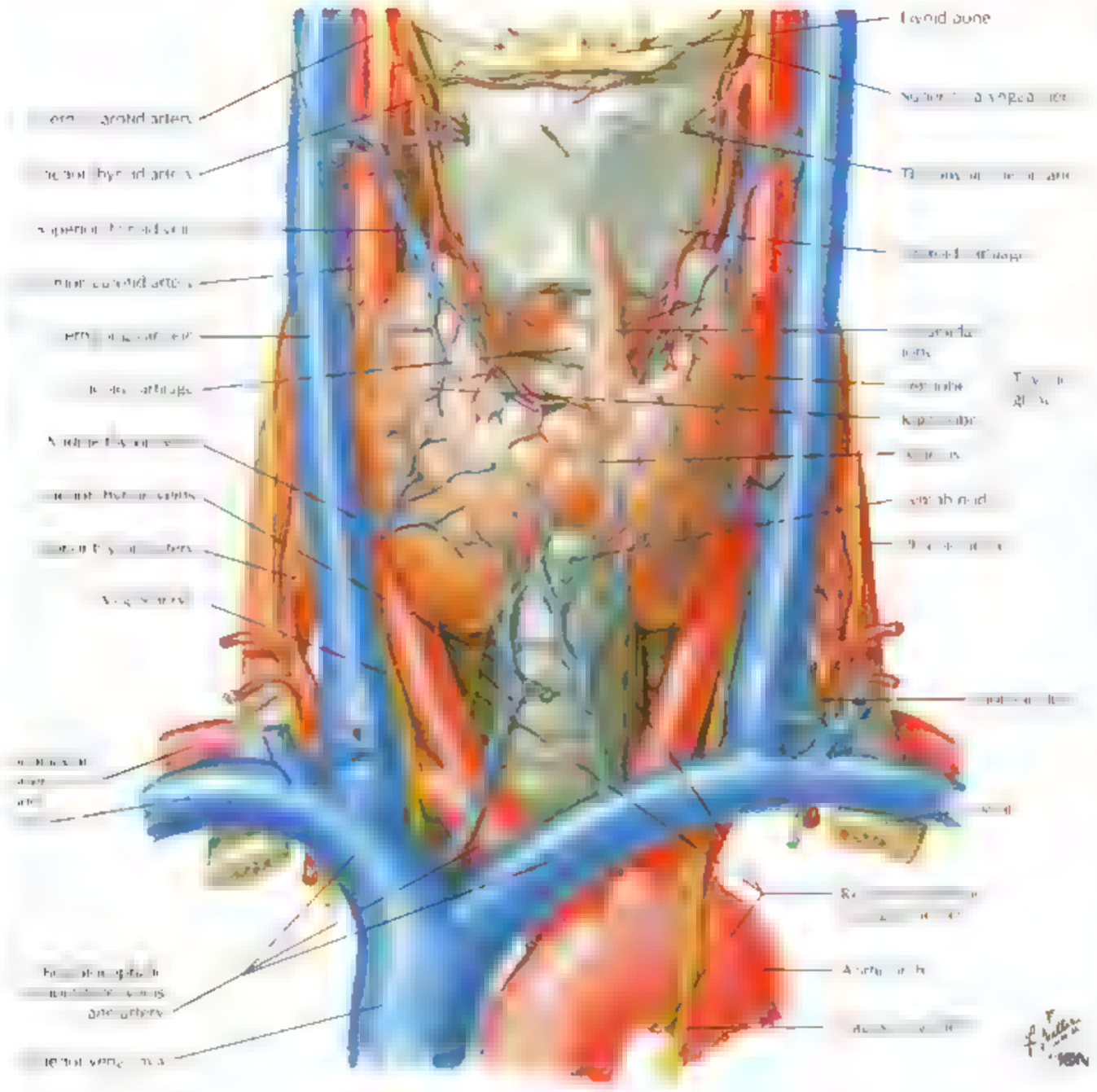

FIGURE 8.8 THYROID GLAND STRUCTURE

The thyroid gland is a duct-less, endocrine gland that [illegible] In the normal population, there is a small percentage [illegible] and has a rich blood supply [illegible]

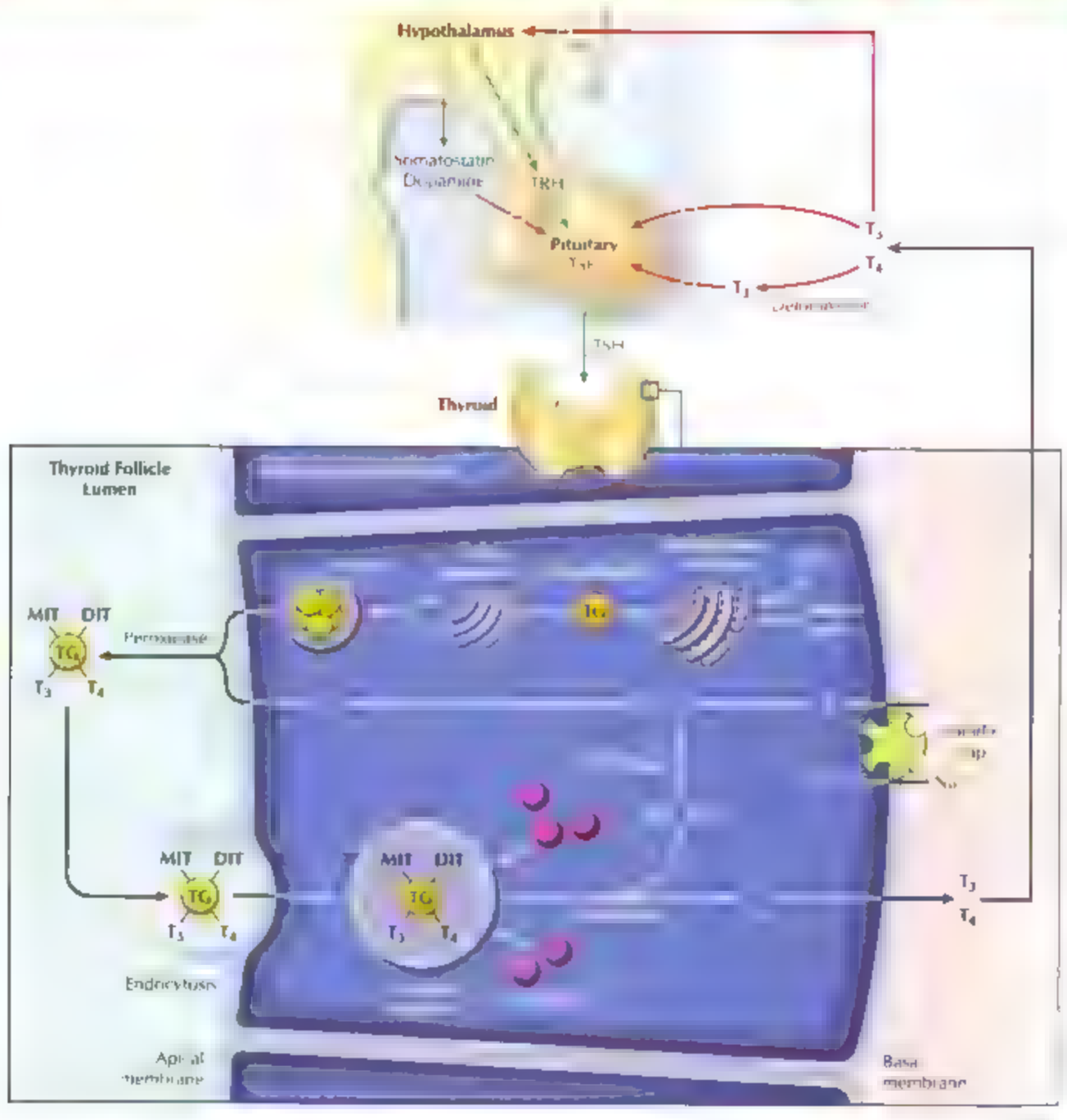

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FIGURE 8.9 THYROID GLAND FUNCTION

The thyroid gland is composed of follicles formed by epithelial cells. These follicular epithelial cells synthesize, store, and secrete thyroxine (T_4) and triiodothyronine (T_3). The thyroid gland actively takes up and concentrates tyrosine molecules. MIT = monoiodotyrosine; DIT = diiodotyrosine. Peroxidase couples these together to form T_3 and T_4 and stores these linked thyroglobulin molecules in the lumen of the follicle. In the presence of TSH, thyroglobulin is endocytosed and T_3 and T_4 are released into the blood. TSH also stimulates the synthesis of T_3 and T_4. Estrogen or ASA will increase the serum thyroxine-binding globulin (TBG), which serves as a reservoir for T_3 and T_4 because T_4 is converted into more active T_3 by peripheral tissues.

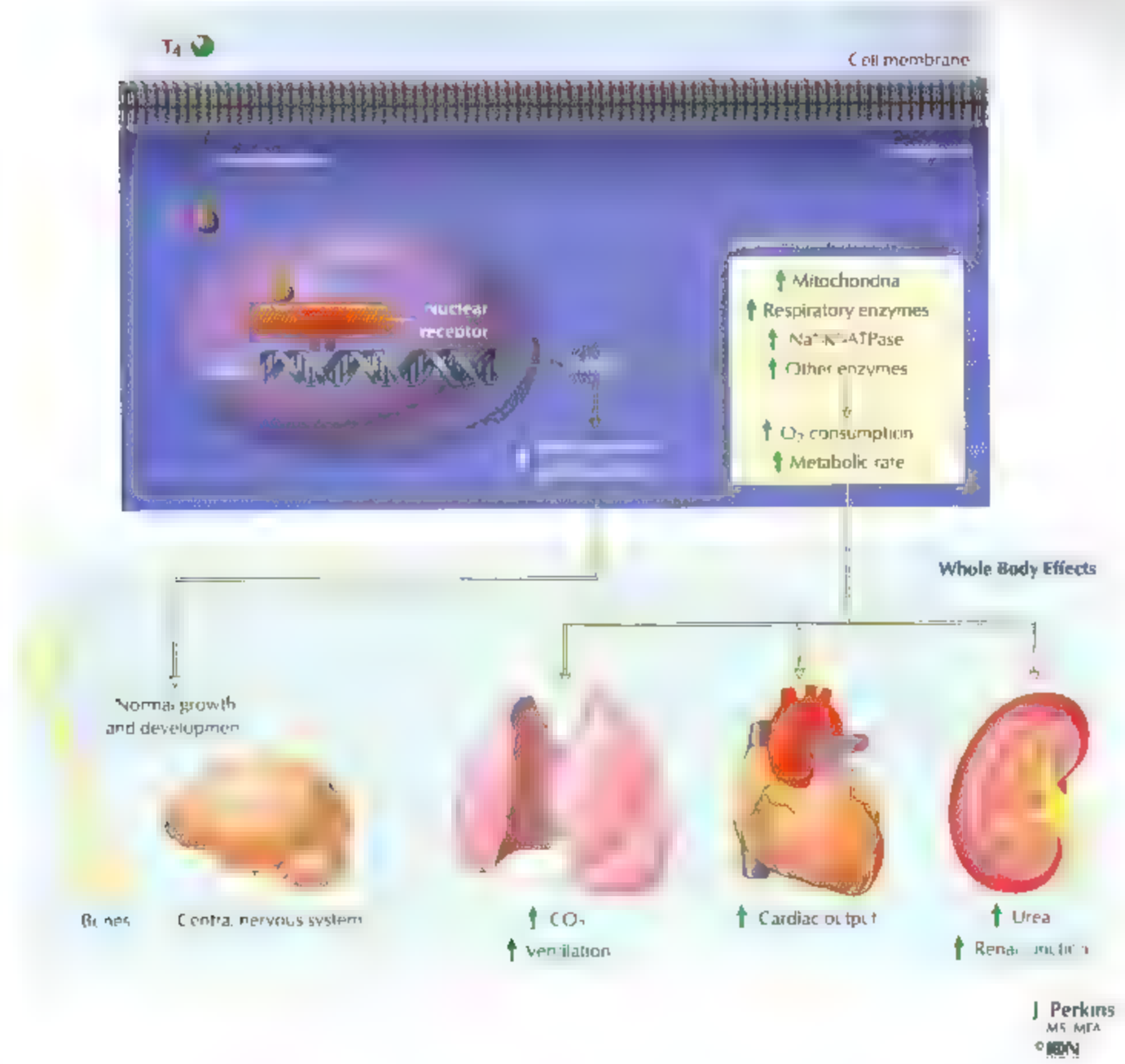

FIGURE 8.10 THYROID HORMONE ACTION

Thyroxine (T_4) is converted to triiodothyronine (T_3) in target tissues. T_3 binds to a nuclear receptor, resulting in transcription of various cellular proteins and enzymes. The net effect is an increase in basal metabolic rate and O_2 consumption. These effects are associated with increased heart rate, lung, and kidney function. T_3 is also important for normal growth and development.

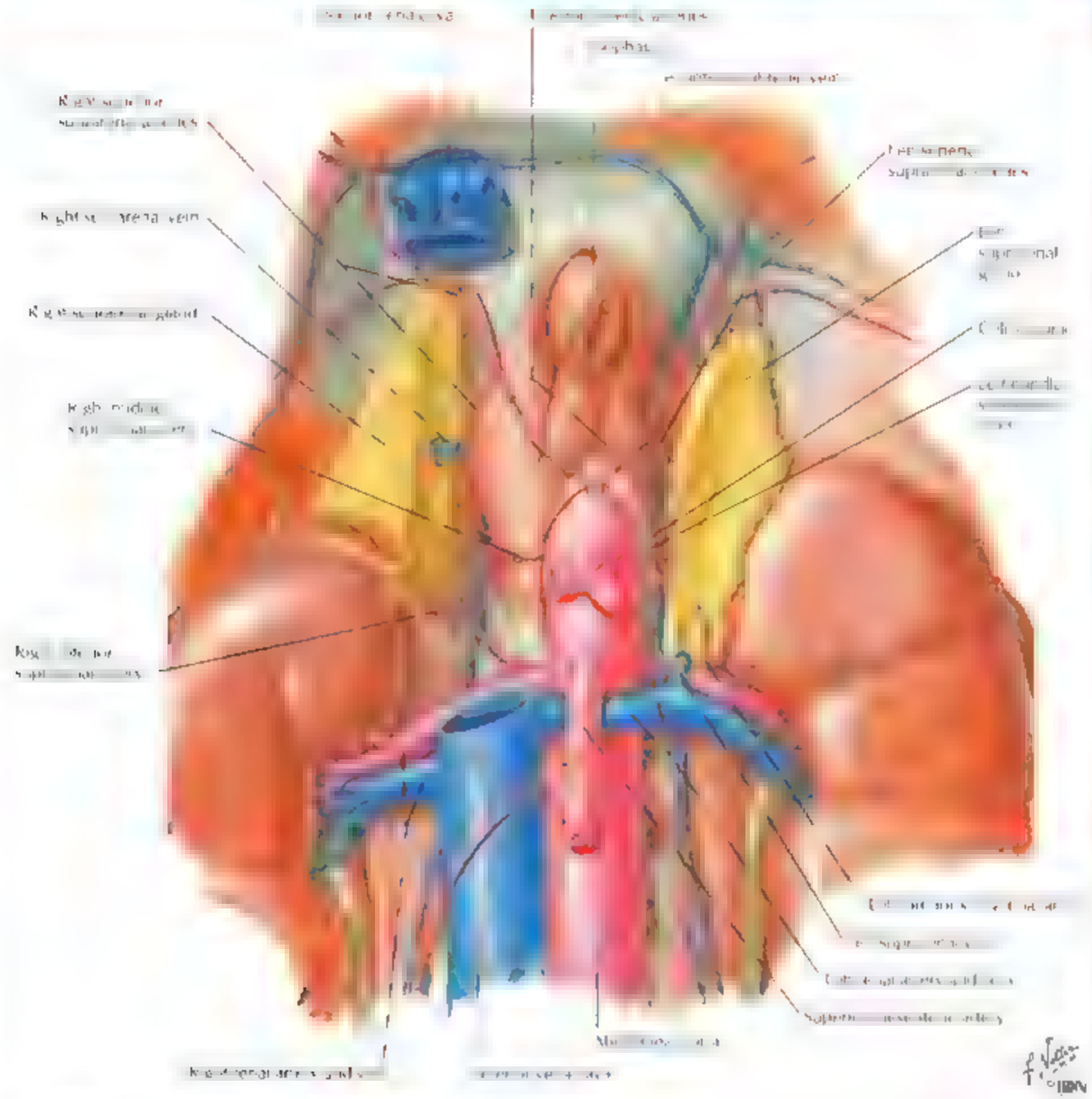

FIGURE 8.11 ADRENAL GLAND STRUCTURE

FIGURE 8.12 ADRENAL GLAND HISTOLOGY

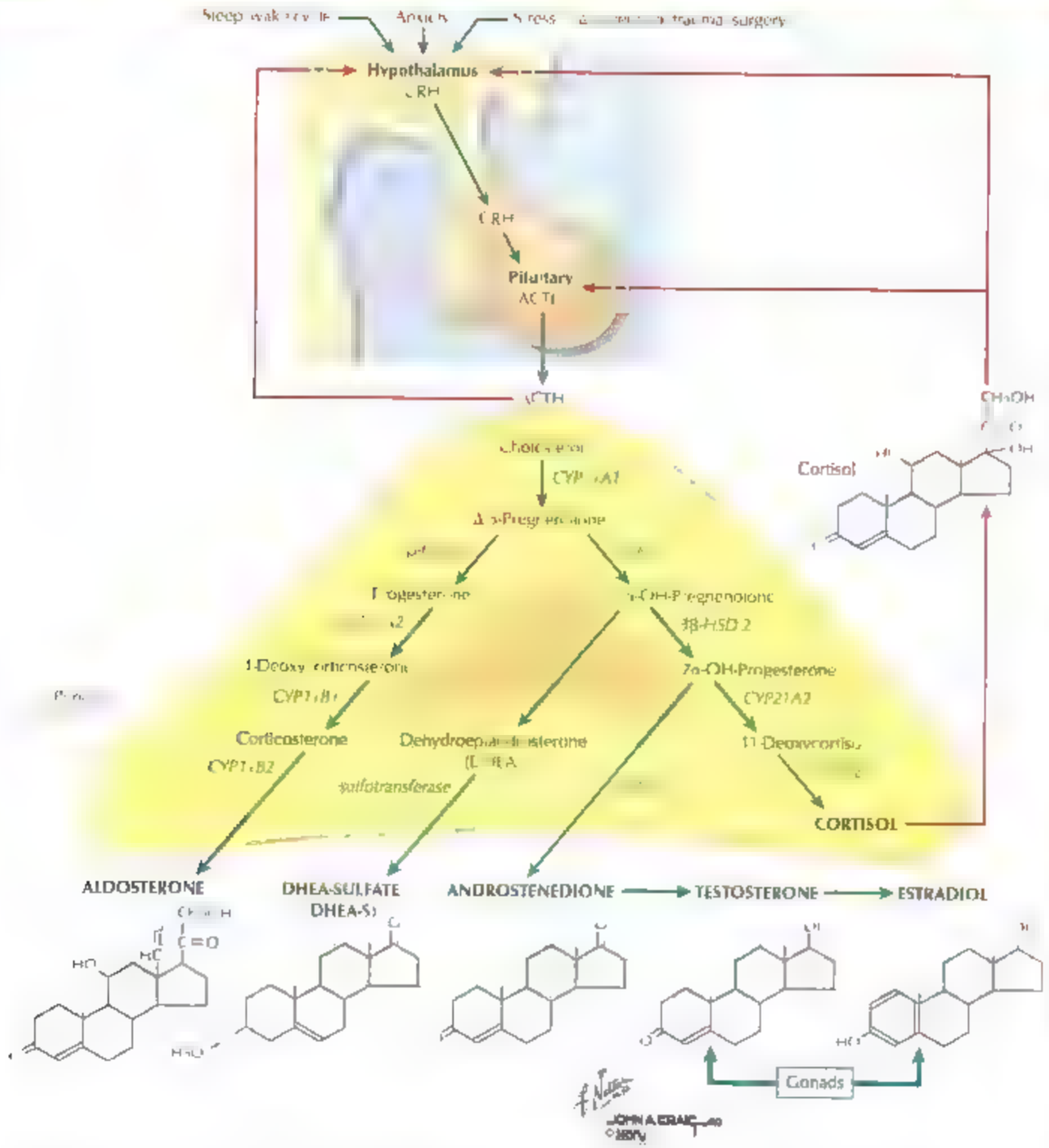

FIGURE 8.13 ADRENAL CORTICAL HORMONES

The adrenal cortex synthesizes and secretes glucocorticoid hormones (e.g. cortisol), mineralocorticoid hormones (e.g. aldosterone), and androgens (e.g. DHEA, androstenedione). Small amounts of the androgens testosterone and estradiol are derived from the adrenal cortex, but the gonads are their primary source. All the adrenal steroid hormones are derived from cholesterol. Cortisol secretion is controlled by the corticotropic hormone ACTH, which is secreted from the anterior pituitary in response to corticotropin-releasing hormone (CRH) from the hypothalamus. ACTH also stimulates the production of adrenal androgens. ACTH is not the primary regulator of aldosterone secretion (see Figure 8.14). Abbreviations: CYP11A1, cytochrome P450 side-chain cleavage; 3β-HSD 2, 3β-hydroxysteroid dehydrogenase; CYP17A1, 17α-hydroxylase/17,20-lyase; CYP21A2, 21-hydroxylase; CYP11B1, 11β-hydroxylase; CYP11B2, aldosterone synthase (11β-hydroxylase/18-hydroxylase/18-oxidase).

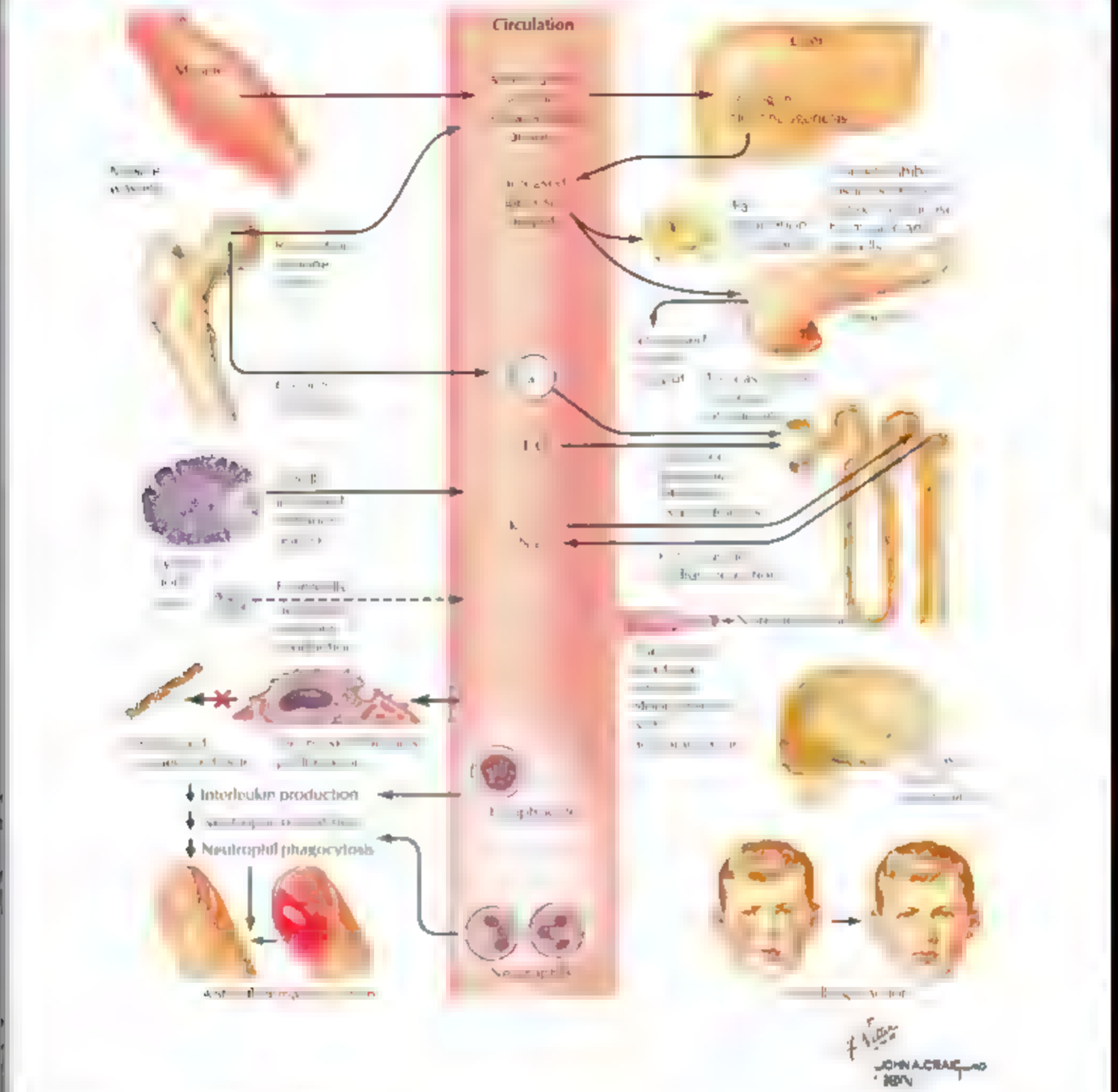

FIGURE B 14 ACTIONS OF CORTISOL

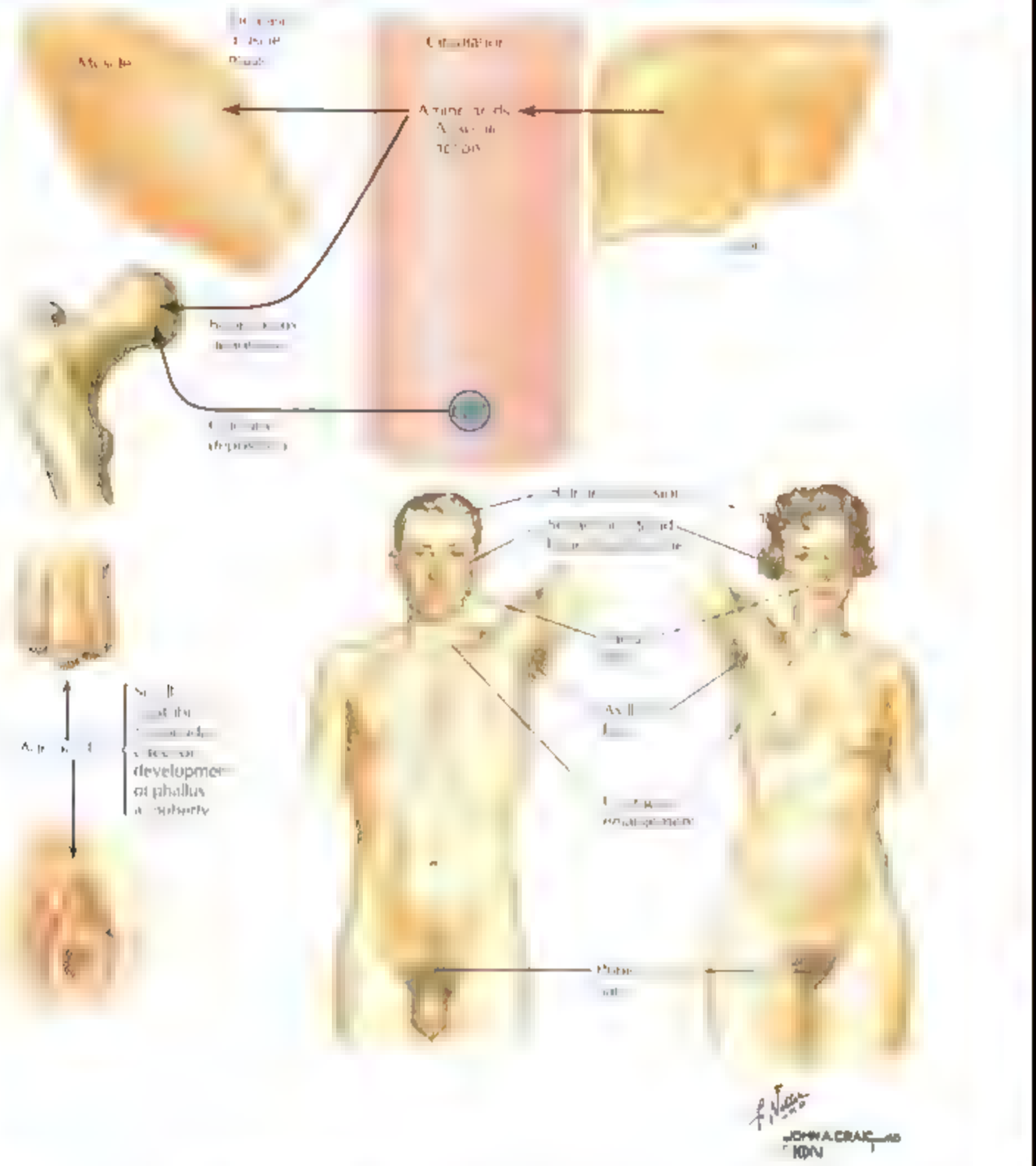

FIGURE 8.15 ACTIONS OF ADRENAL ANDROGENS

The adrenal androgens dehydroepiandrosterone (DHEA) and androstenedione do not have major effects in males, where the testicular testosterone predominates. In females, the adrenal glands are the primary source of sexual hair androgens. These adrenal androgens are responsible for the growth of pubic and axillary hair. Excess adrenal androgens produce hirsutism (excessive growth of facial hair) and masculinization of the external genitalia and other secondary sexual characteristics—a process termed adrenarche (see Figure 8.25). The general effects of androgens are anabolic, leading to increased muscle mass and bone density. The latter is the reason postmenopausal women are prone to osteoporosis.

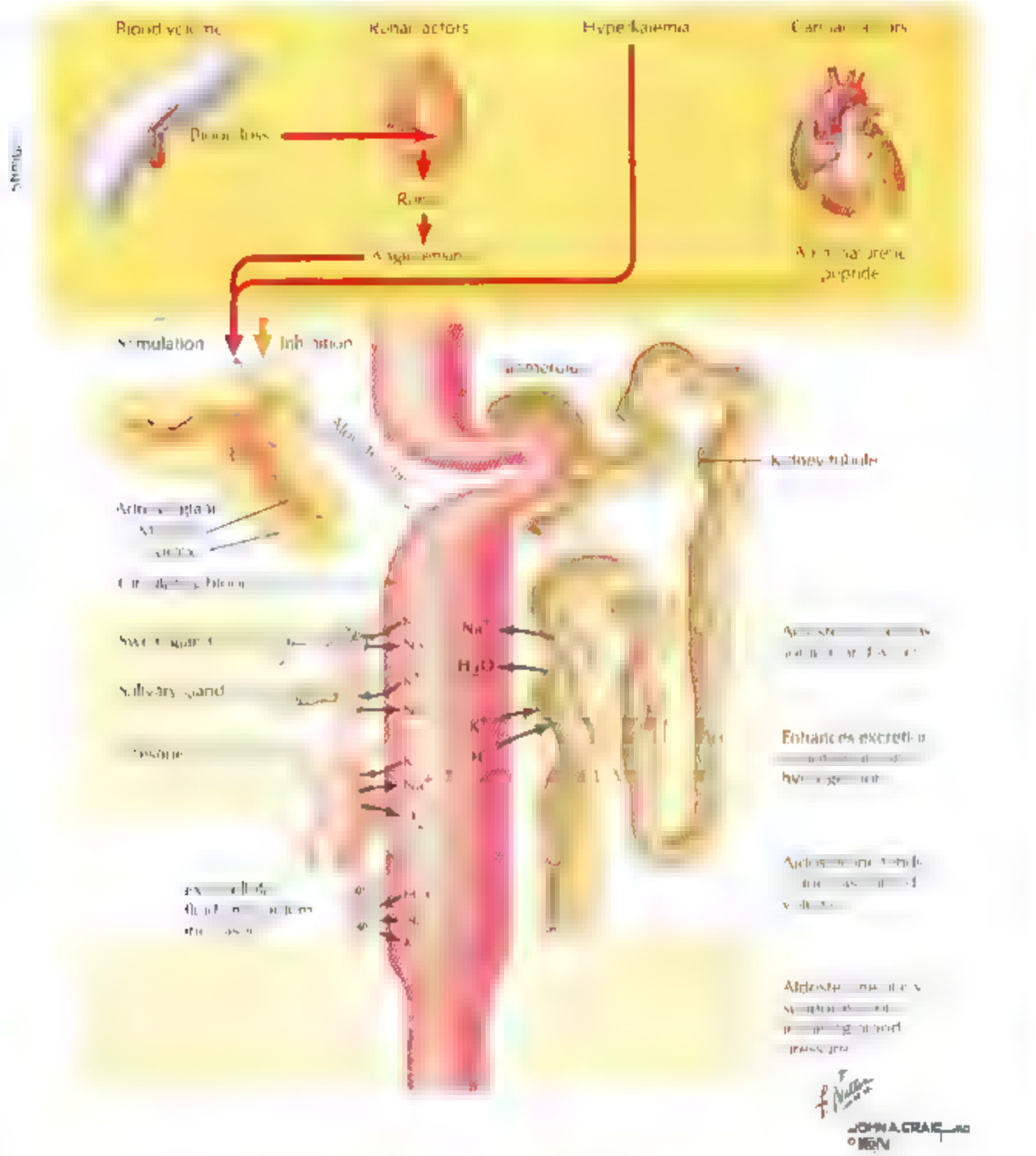

FIGURE 8.16 ACTIONS OF ALDOSTERONE

When the ECF and blood volumes are reduced (e.g. by hemorrhage), renin is released from the kidney, which in turn increases angiotensin II levels. Angiotensin II stimulates aldosterone secretion by the adrenal gland. Aldosterone acts on the kidney to promote Na+ and water reabsorption, a response that serves to increase ECF and blood volume. The kidneys are the most important organs in this response (see Figure 8.15), and when the ECF volume is increased, atrial natriuretic peptide is secreted and acts on the adrenal cortex to diminish aldosterone secretion. Aldosterone acts primarily on the kidney to stimulate Na+ reabsorption, which also stimulates water reabsorption. Aldosterone also enhances the excretion of K+ and H+.

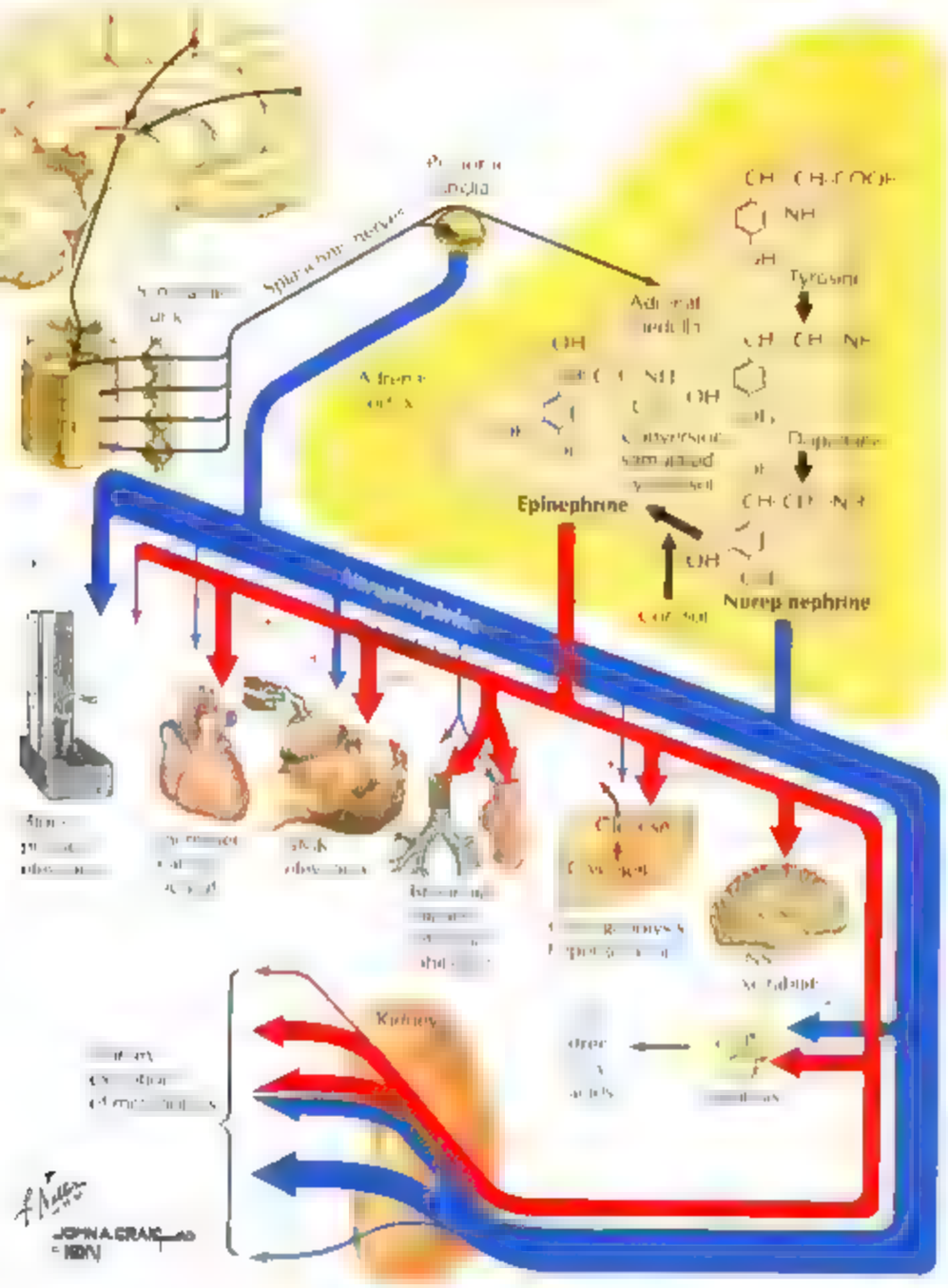

FIGURE 8.17 FUNCTION OF THE ADRENAL MEDULLA

The adrenal medulla produces epinephrine and norepinephrine. The medullary cells are stimulated by preganglionic fibers of the sympathetic division of the autonomic nervous system. In response to stress, they release epinephrine and norepinephrine into the blood. In the blood, epinephrine acts on the heart, skeletal muscle, liver, and adipose tissue. The effects of norepinephrine in the blood are similar to those of norepinephrine released by the postganglionic neurons of the sympathetic nervous system.

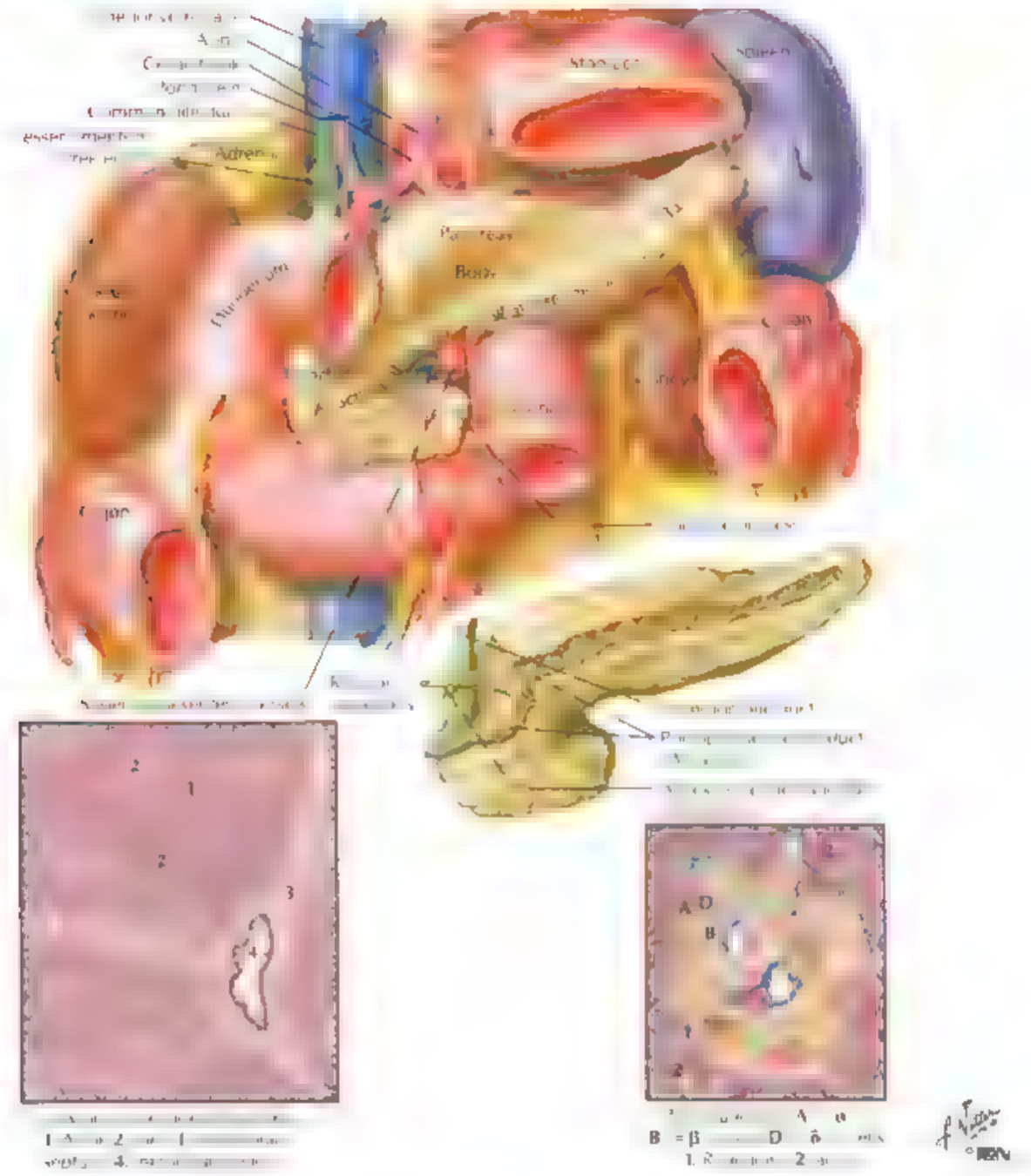

FIGURE 8.18 STRUCTURE OF THE ENDOCRINE PANCREAS

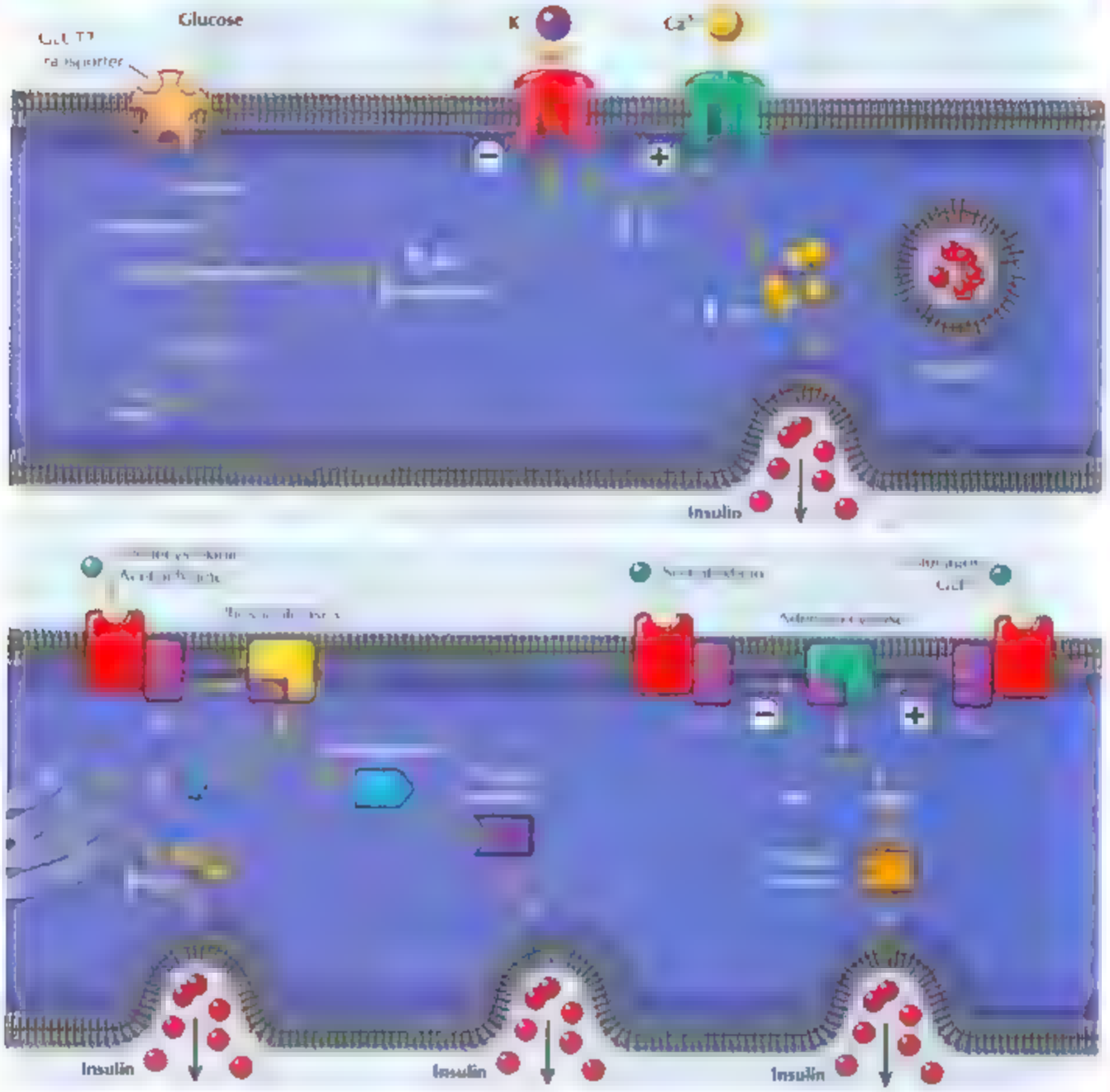

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FIGURE 8.19 INSULIN SECRETION

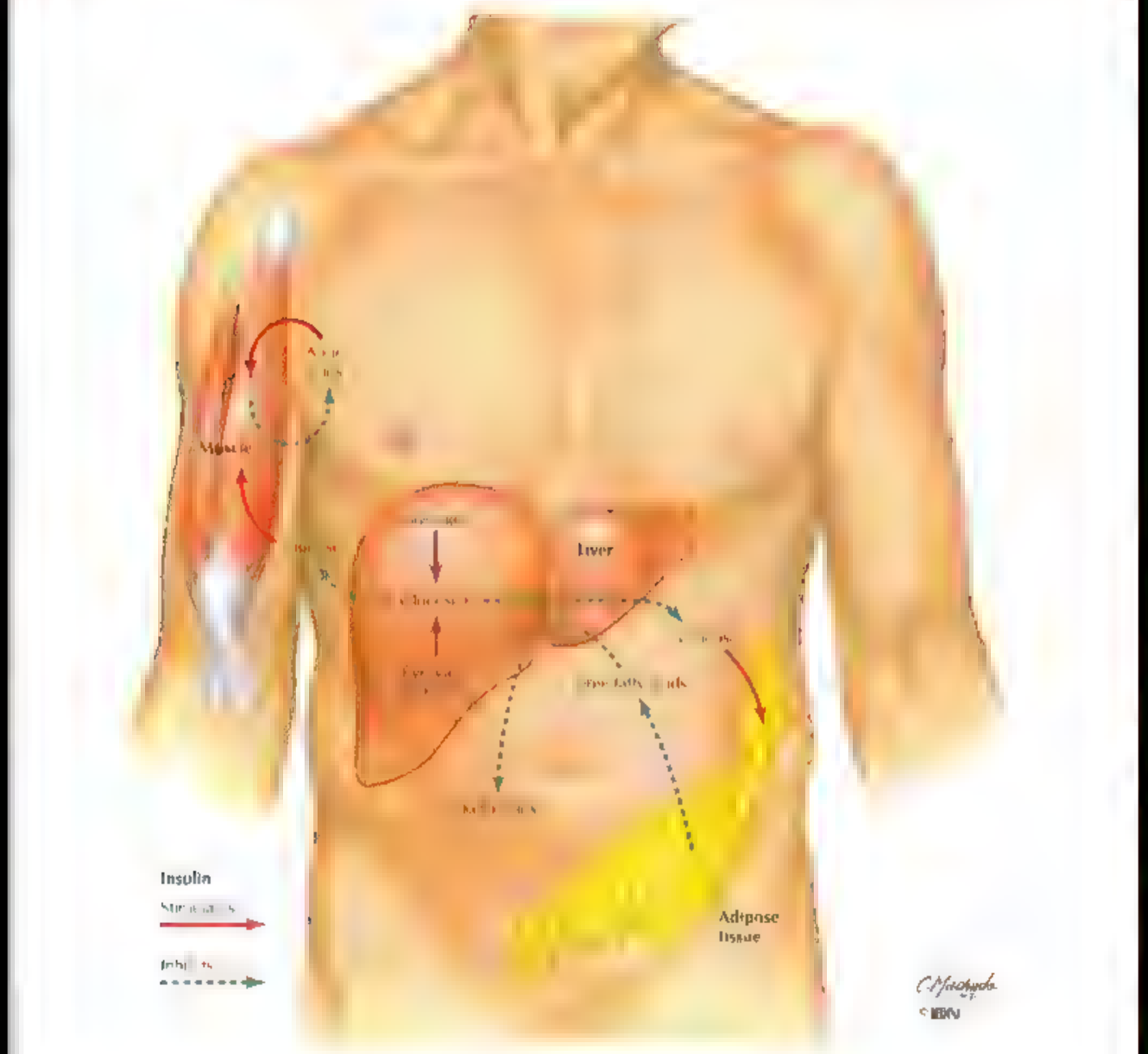

FIGURE 8.20 ACTIONS OF INSULIN

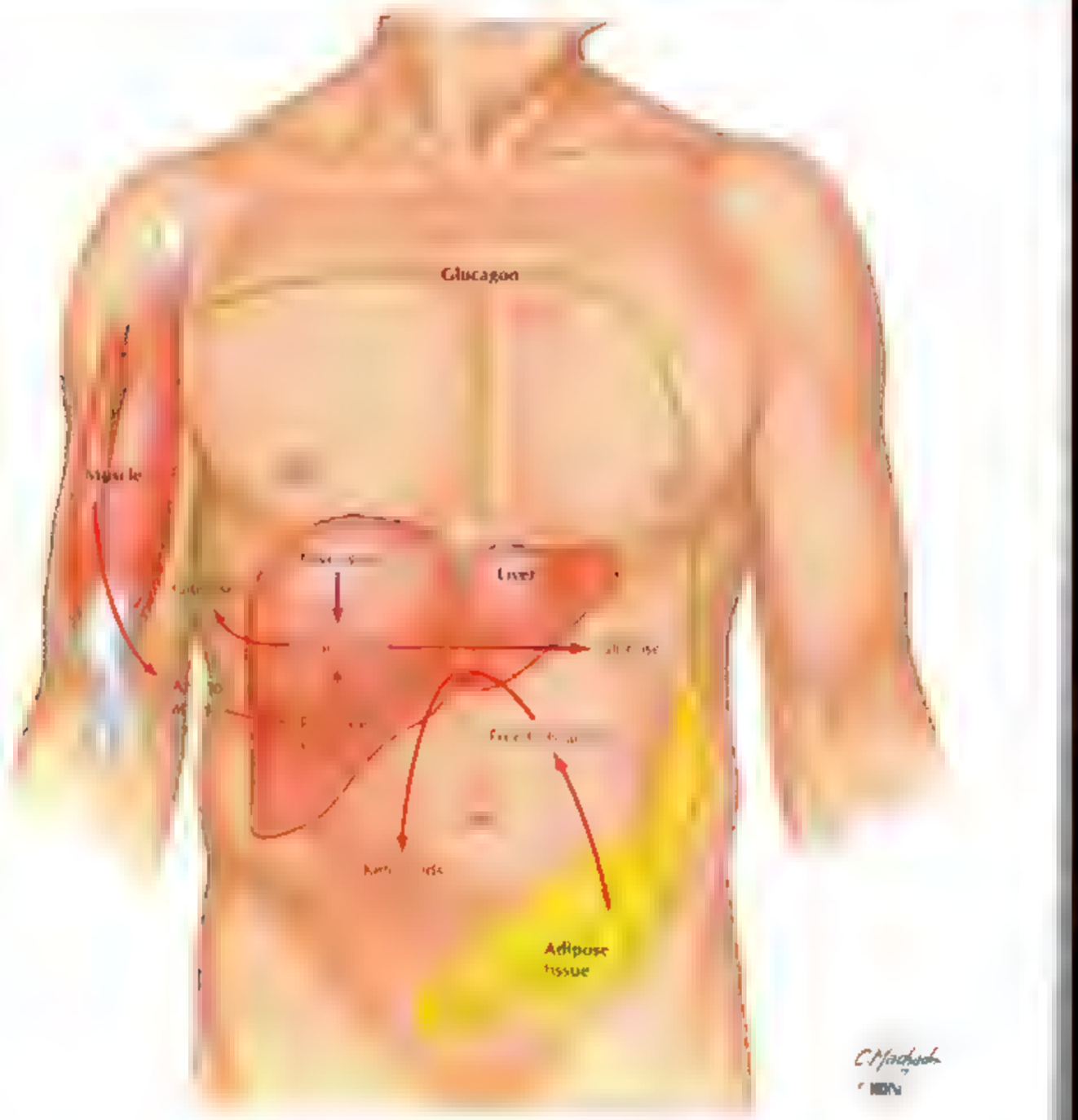

FIGURE 8.21 ACTIONS OF GLUCAGON

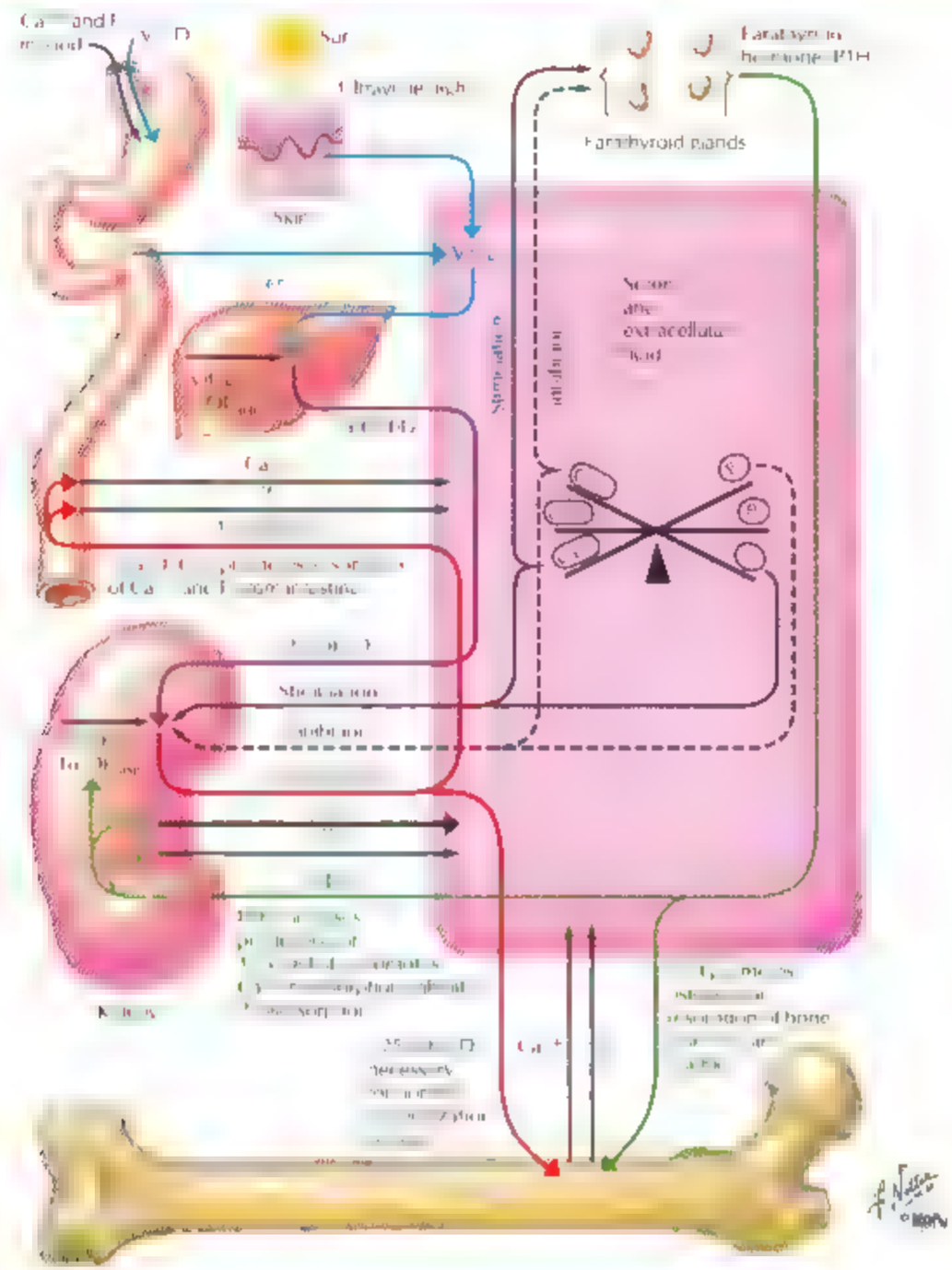

FIGURE 8.22 PARATHYROID HORMONE

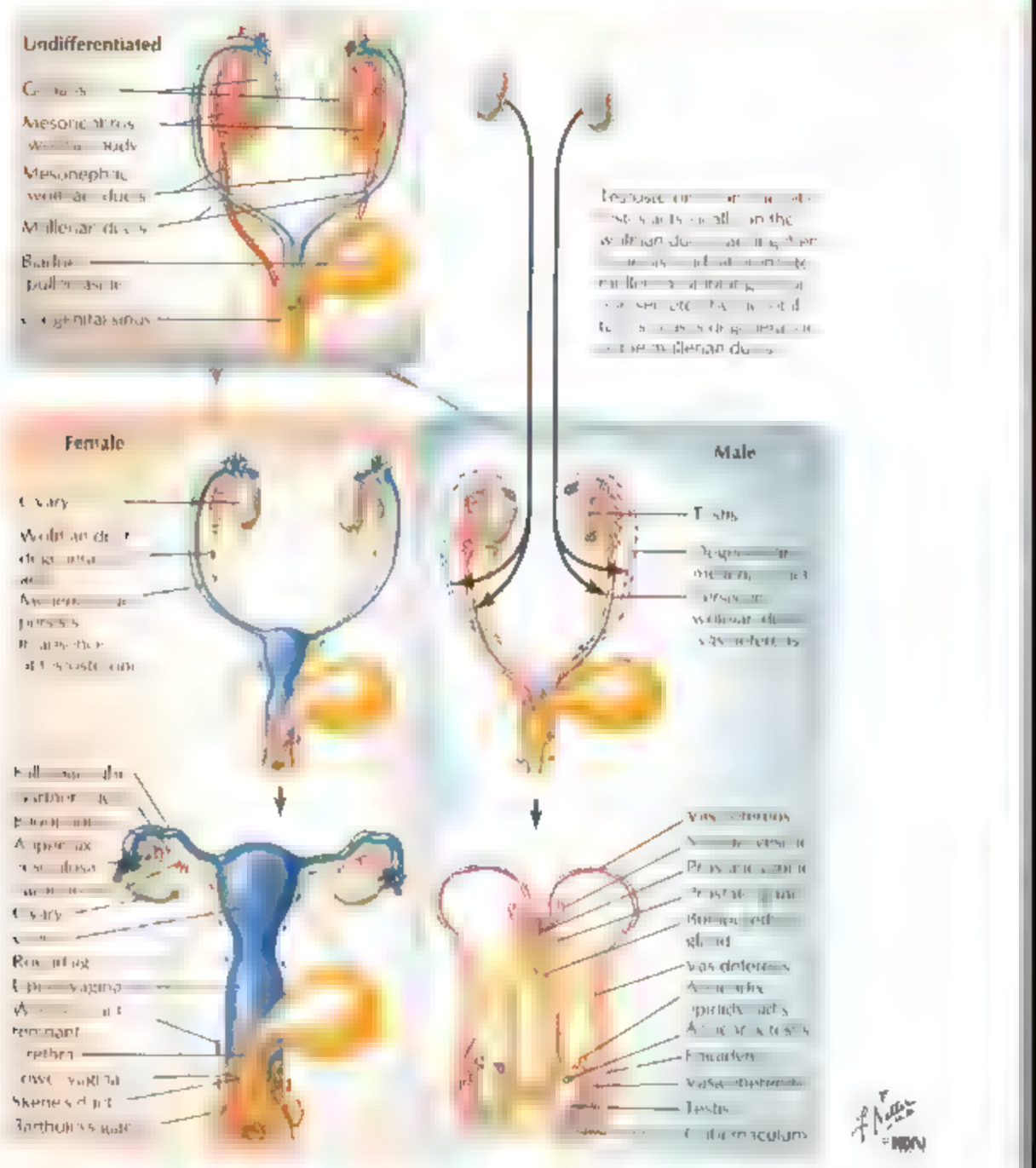

FIGURE 8.23 GONAD AND GENITAL DUCT FORMATION

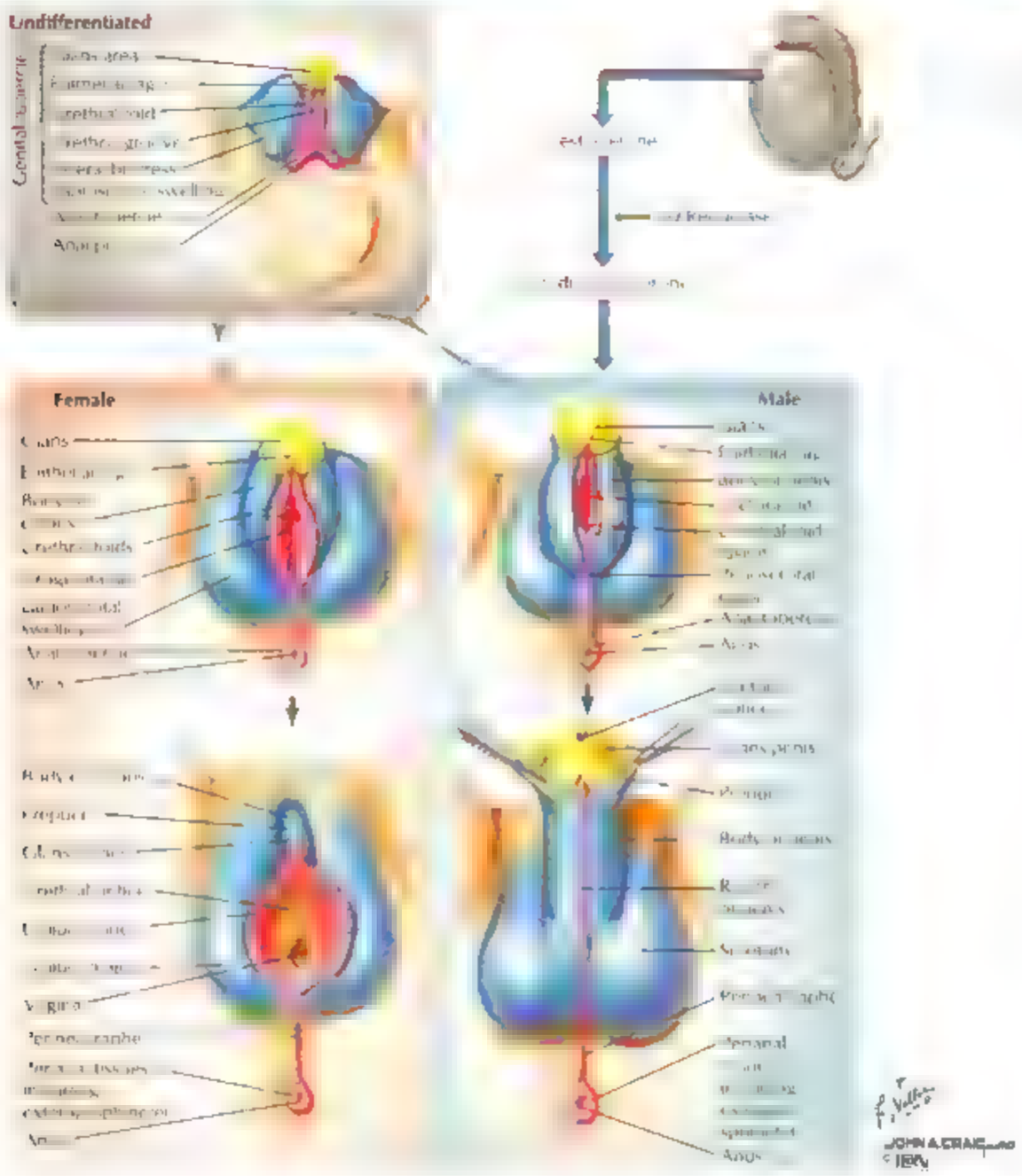

FIGURE 8.24 DIFFERENTIATION OF THE EXTERNAL GENITALIA

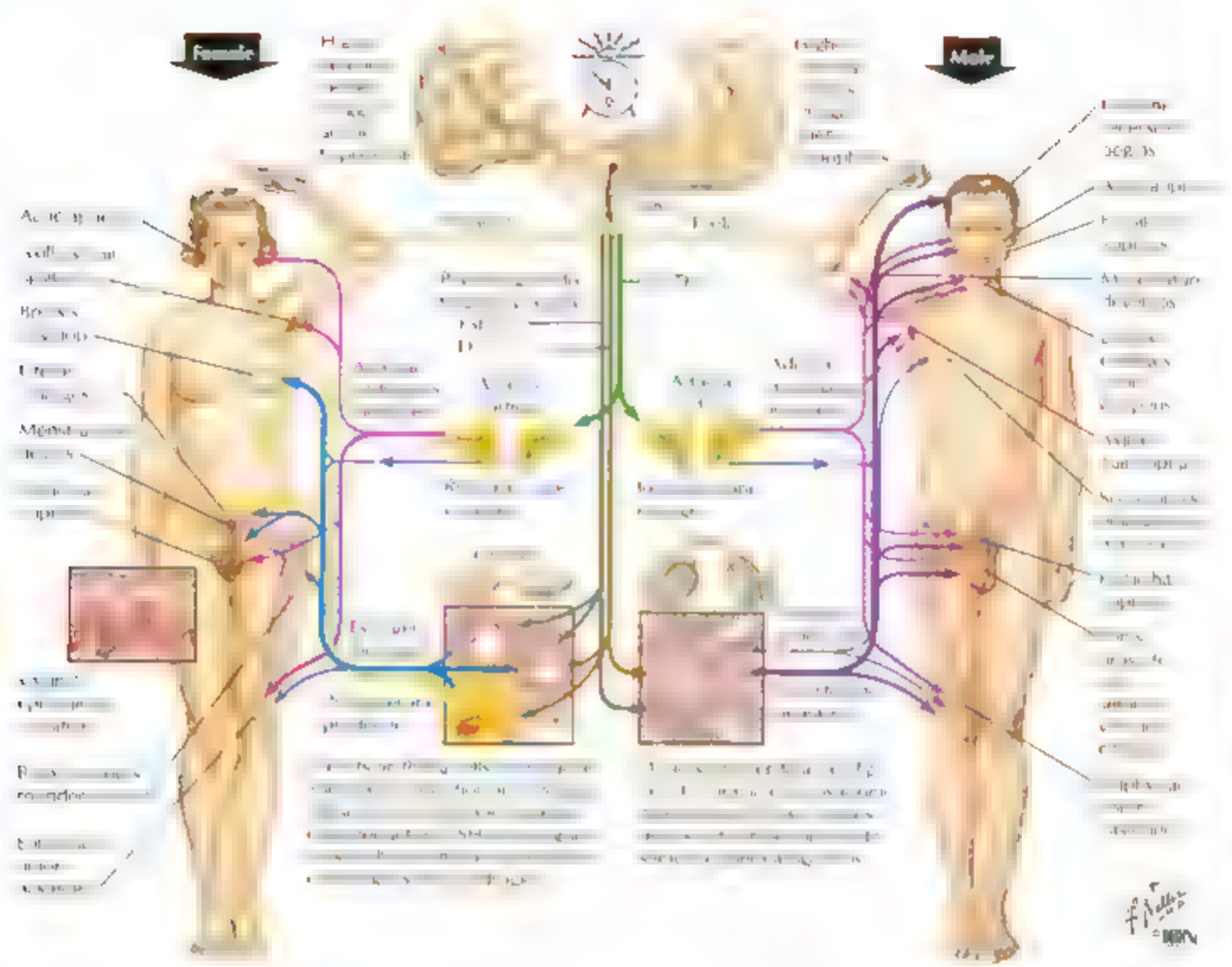

FIGURE 8.25 PUBERTY

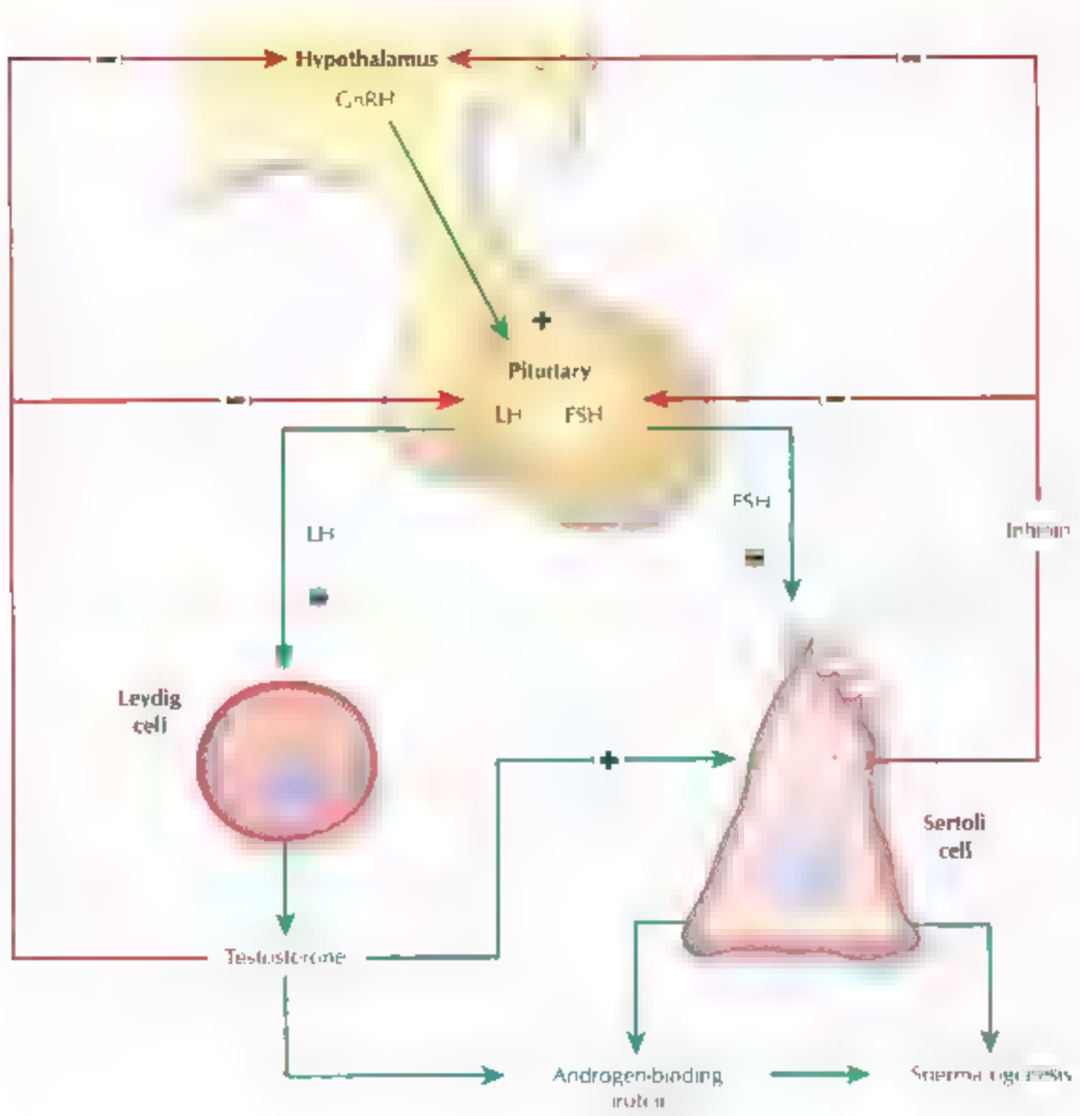

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FIGURE 8.26 CONTROL OF TESTICULAR FUNCTION

The testes are under the control of luteinizing hormone (LH) and follicle stimulating hormone (FSH) and their secretion is regulated by gonadotropin releasing hormone (GnRH) from the hypothalamus. LH acts on the Leydig cells to stimulate their production of testosterone. FSH acts on the Sertoli cells to stimulate their production of androgen-binding protein which concentrates testosterone in the seminiferous tubules to promote spermatogenesis. Testosterone provides negative feedback inhibition of LH release, whereas inhibin production by the Sertoli cells provides negative feedback inhibition of FSH secretion.

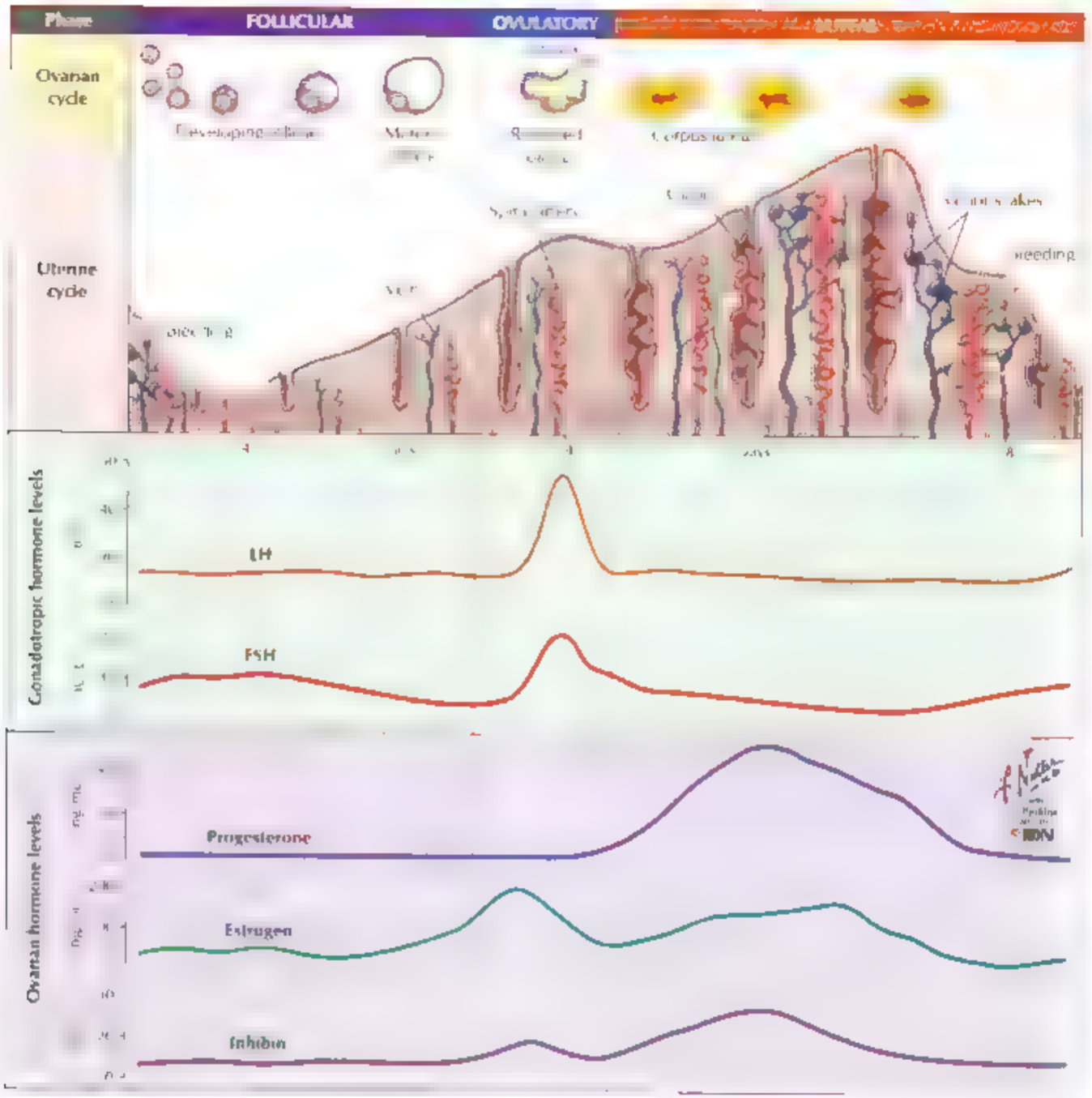


FIGURE 8.27 MENSTRUAL CYCLE

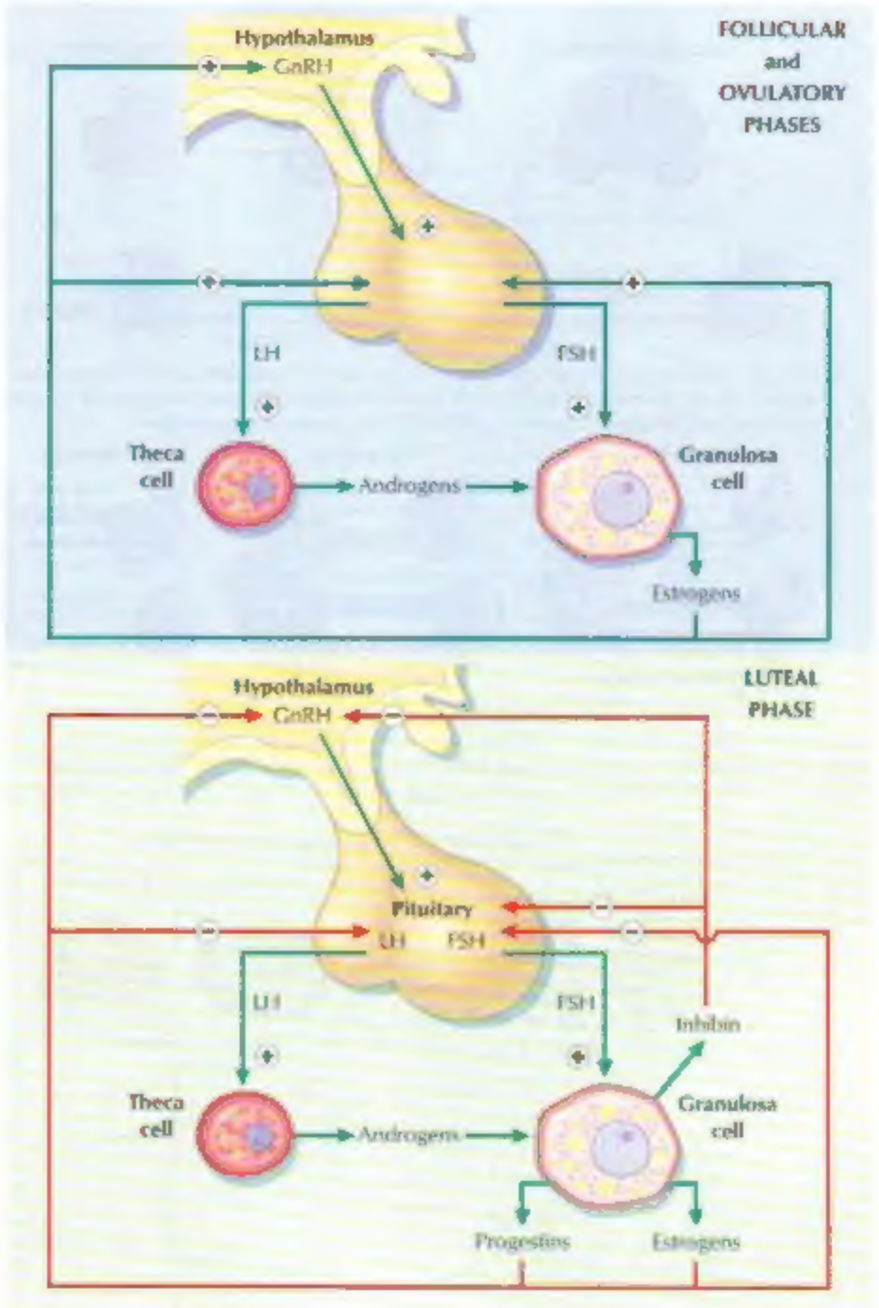
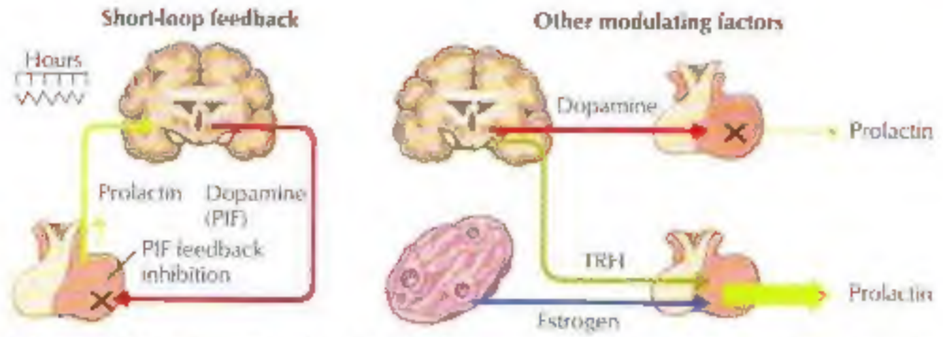


FIGURE 8.28 HORMONAL REGULATION OF THE MENSTRUAL CYCLE

Upper panel: During the follicular phase, the granulosa cells in a selected follicle proliferate and produce estradiol in response to follicle-stimulating hormone (FSH). At the same time, luteinizing hormone (LH) stimulates the theca cells to produce androgens. The androgens produced by the theca cells diffuse into the granulosa cells, where they are converted to estradiol. This leads to a large increase in estradiol production. The rising levels of estradiol and, to a lesser degree, progestins (e.g., progesterone), feed back on both the hypothalamus and pituitary to stimulate (i.e., positive feed back) a surge in GnRH secretion followed by peaks in LH and FSH secretion, which then induce ovulation. *Lower panel:* Following ovulation, the remaining follicular cells transform into the corpus luteum in response to LH and produce large amounts of progesterone and estradiol. During this luteal phase, the granulosa cells also produce inhibin. Together, progesterone, estradiol, and inhibin feed back on the pituitary to suppress LH and FSH secretion. In the absence of fertilization of the released egg, the corpus luteum regresses and menses begins.



Prolactin-inhibiting factor (PIF), thought to be dopamine, modulates prolactin secretion. Elevated prolactin levels increase PIF secretion and cause feedback inhibition of prolactin secretion (short-loop feedback inhibition). Estrogen and TRH stimulate prolactin secretion

Prolactin, along with GH, estrogen, progesterone, and adrenocorticoids, is necessary for breast development

In pregnancy, elevated prolactin, estrogen, and progesterone increase alveolobular development. High estrogen levels inhibit lactation

Sudden decrease in estrogen and progesterone in presence of prolactin results in milk production. Oxytocin stimulates milk release

Variations in prolactin levels by age or condition

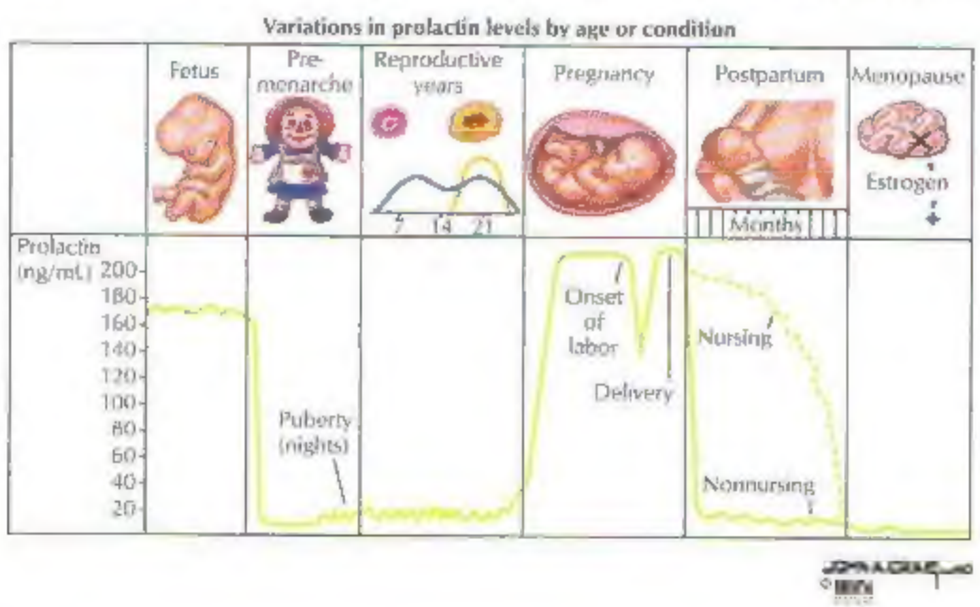


FIGURE 8.29 LACTATION

The role of prolactin in breast development, pregnancy, and lactation is summarized in this figure. Although prolactin is under dual hypothalamic control, it is unique because its secretion is under the inhibitory control of dopamine (PIF). *Abbreviation: GH,* Growth hormone.

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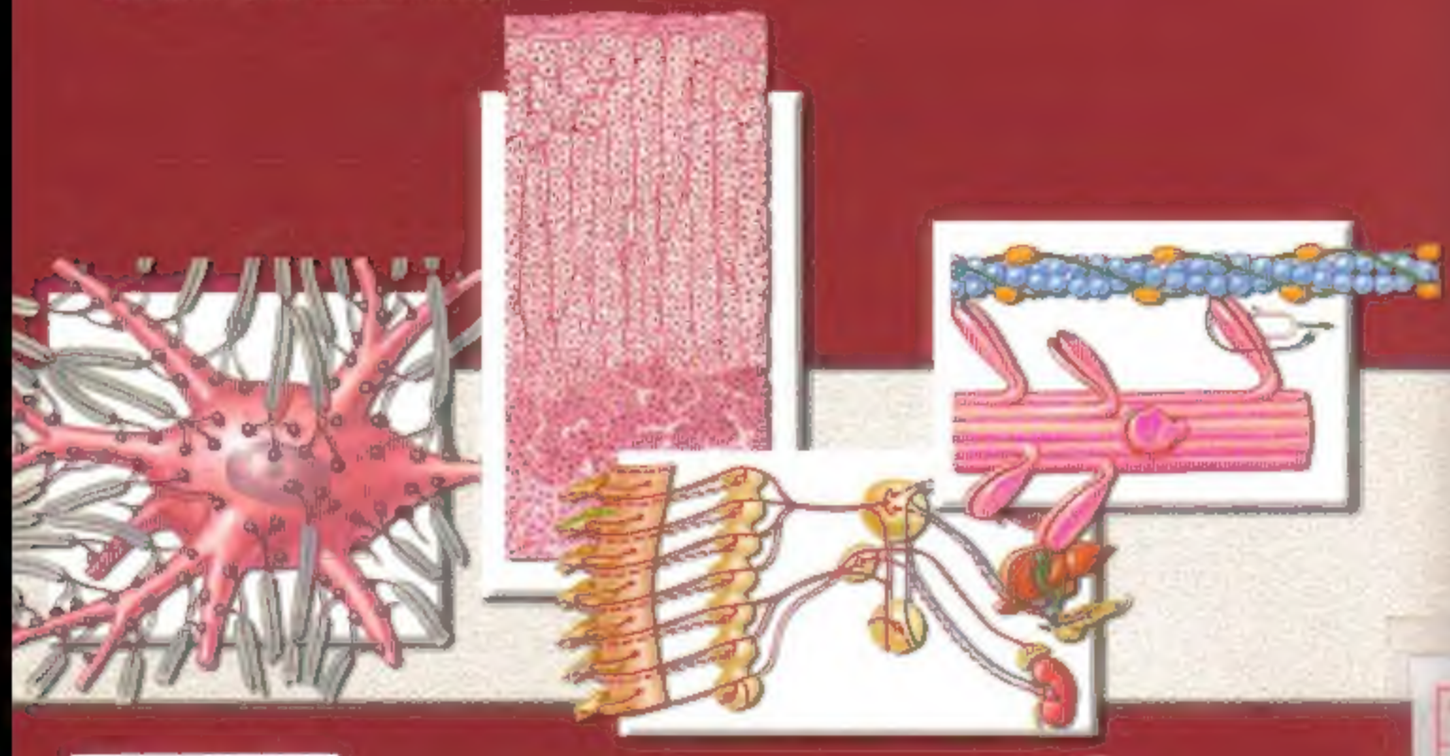

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